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ABSTRACT: Sixteen new genera and forty-three species, of which thirty-one are new, of microplankton are described from western Australian Cretaceous (Albian to Campanian) sediments. The new forms include dinoflagellates, hystrichospheres, and others of uncertain affinity.

Microplankton from Australian Cretaceous sediments

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INTRODUCTION

This paper is concerned mainly with the classification and description of some new types of microplankton from Cretaceous (upper Albian to Campanian) deposits in the Carnarvon and Perth Basins of Western Australia. Suitable samples for the study were provided by the West Australian Petroleum Pty. Ltd. ("Wapet") from the Rough Range South no. 1 bore and the Perth Basin, and by the Bureau of Mineral Resources from the Brickhouse Bore, and we wish to acknowledge our indebtedness to both organisations for their helpful cooperation in this respect.

Both series of samples from the Carnarvon Basin have been dated by means of foraminifera, most of the Rough Range South series by Dr. M. F. Glaessner (unpublished report to Wapet), the Brickhouse Bore series by H. S. Edgell (1957). The samples from the Perth Basin are less exactly dated. The ages herein suggested for the various sediments from this area are based, in the absence of the more generally accepted criteria, almost entirely on microplankton correlations with the Rough Range South and Brickhouse Bore sequences.

LOCATION AND AGE OF SEDIMENTS

WESTERN AUSTRALIA

I. Carnarvon Basin

- a) Exmouth Gulf area: Wapet's Rough Range South no. 1 bore (lat. 22°37'17.5" S., long. 113°57'37.6" E.); Toolonga calcilutite, core 56 (2390–2393 ft.), age: probably Campanian; Toolonga calcilutite, cores 58–59 (2429–2447 ft.), age: probably Santonian; upper Gearle siltstone, cores 61–67 (2500–2696 ft.), age:

Turonian; upper Gearle siltstone, core 68 (2717–2725 ft.), age: Cenomanian; lower Gearle siltstone, core 69 (2748–2758 ft.), age: Albian to Cenomanian; lower Gearle siltstone, cores 70–71 (2758–2867 ft.), age: Albian.

- b) Central region: 10 miles southeast of Carnarvon; Brickhouse Bore between 435 and 715 ft., age: Campanian (Edgell, 1937); at 1210 ft., age: Cenomanian or Turonian (D. J. Belford, personal communication), probably Cenomanian (authors).

II. Perth Basin

a) Gingin area:

- 1) Four miles north of Gingin, Wapet's seismic shot hole B1, between 120 and 180 ft., age: probably upper Turonian to middle Senonian (authors); between 190 and 230 ft., age: (?) upper Albian to Cenomanian (authors).
- 2) Molecap greensand (McWhae et al., 1958, p. 116), age: probably upper Turonian to middle Senonian (authors).

b) Metropolitan area:

Osborne formation (McWhae et al., 1958, p. 43); Subiaco Bore, at 358 ft.; Fremantle Traffic Bridge bore no. 5, at 100 ft., age: (?) upper Albian to Cenomanian (authors).

VICTORIA

Nelson, Parish of Glenelg, Victoria Department of Mines Bore, southwest end of bridge over Glenelg River, at 5304 ft., 5782 ft., and 6233 ft., age: Senonian (Maestrichtian to Santonian of authors).

SYSTEMATIC DESCRIPTIONS

DINOFLAGELLATES
Family GYMNODINIDAE
Genus GYMNODINIUM Stein, 1878

Gymnodinium westralium Cookson and Eisenack

Gymnodinium cf. *heterocostatum*. DEFLANDRE AND COOKSON, 1955, Australian Jour. Mar. Freshwater Res., vol. 6, p. 248, pl. 1, fig. 7

Gymnodinium westralium COOKSON AND EISENACK, 1958, Roy. Soc. Victoria, Proc., vol. 70, p. 25, pl. 1, fig. 9.

Gymnodinium westralium has already been recorded from a number of Western Australian Upper Cretaceous deposits. During the present investigation, isolated examples of similar type have been recovered from cores 56–63 of the Rough Range South no. 1 bore (2390–2514 ft.), which represent the Toolonga calcilutite and the upper Gearle siltstone, and from the Brickhouse Bore, between 535 and 715 ft.

There is little or no doubt that *Gymnodinium westralium*, like the several closely related European species, is an Upper Cretaceous form, with its main development in the Turonian and Senonian. It is possible that more than one species of *Gymnodinium* has been included in this record of *Gymnodinium westralium*, but a richer occurrence will be necessary before more detailed speciation can be attempted.

Family DEFLANDREIDAE
Genus DEFLANDREA Eisenack, 1938

Deflandrea serratula Cookson and Eisenack

Deflandrea serratula COOKSON AND EISENACK, 1958, Roy. Soc. Victoria, Proc., vol. 70, p. 28, pl. 4, fig. 4.

Age and occurrence: Campanian to lower Maestrichtian: Korojon calcarenite, Wapet's Rough Range no. 4 bore, 1380–1386 ft. Campanian: Brickhouse Bore, 435 and 595 ft. Probably Santonian to Campanian: Toolonga calcilutite, Rough Range South no. 1 bore, cores 58–59 (2429–2447 ft.).

Comments: The new examples of *Deflandrea serratula* show that the serrations, originally noted as occurring along the sides of the epitheca, extend also to the hypotheca. *Deflandrea serratula* appears to be restricted to the Senonian.

Deflandrea minor Cookson and Eisenack,
new species

Plate 1, figures 1–4

Holotype: Nat. Mus. Vic. no. P17793 (fig. 1).

Age and occurrence: Probably upper Turonian to middle Senonian: Molecap greensand, north of Gingin, Wapet's seismic shot hole B1, at 170 ft. Turonian: upper Gearle siltstone, Rough Range South no. 1 bore, cores 61–63 (2500–2514 ft.).

Description: Shell approximately oval, divided by a shallow but relatively broad girdle. The epitheca tapers to a short truncate or concave apex; the hypotheca is broadly rounded, with one or two small lateral points of unequal size. A rather broad longitudinal furrow is usually evident. The capsule is circular in outline and does not fill the shell laterally. The shell membrane is sparsely covered with small spines, which tend to be linearly arranged on the general surface as well as on the borders of the girdle and longitudinal furrow. The wall of the capsule is thin and smooth. The pylome is small and semicircular to trapezoid.

Dimensions: Holotype: 52 μ long; 40 μ broad; capsule 33 μ . Range: 45–65 μ long; 37–43 μ broad.

Comments: It seems probable that the single rather imperfect specimen from the Molecap greensand referred to as *Palaeohystrichophora minuta* by Deflandre and Cookson (1955, text-fig. 4) is identical with *Deflandrea minor* sp. nov. However, as neither author knows the whereabouts of the type of *Palaeohystrichophora minuta*, there is no way of establishing such an identity.

Deflandrea echinoidea Cookson and Eisenack,
new species

Plate 1, figures 5–6

Holotype: Nat. Mus. Vic. no. P17794 (fig. 5).

Age and occurrence: Senonian (probably Campanian and Santonian): Toolonga calcilutite, Rough Range South no. 1 bore, core 56 (2390–2393 ft.) and core 59 (2435–2447 ft.). Probably upper Turonian to middle Senonian: north of Gingin, seismic shot hole B1, at 160 ft.

Description: Shell rather flat, somewhat pentagonal with convex sides, divided unequally by a circular girdle with high borders into a smaller hypotheca, with a clearly defined pointed horn on one side and occasional indications of a smaller one on the other side, and a larger epitheca which narrows toward a variously shaped apex, usually carrying a tuft of spines. The broad longitudinal furrow is restricted to the hypotheca. The shell membrane is thin and fairly densely covered with thin, stiff spines (up to 5 μ long). The capsule is spherical, rather thin-walled, and fills the shell laterally. A narrow pylome is sometimes developed.

Dimensions: Holotype: 80 μ long; 57 μ broad; capsule ca. 43 μ . Range: 67–86 μ long; 50–57 μ broad.

Deflandrea tripartita Cookson and Eisenack,
new species

Plate 1, figure 10

Holotype: Nat. Mus. Vic. no. P17795.

Age and occurrence: Probably upper Turonian to middle Senonian: north of Gingin, Wapet's seismic shot hole B1, at 160 ft.

AUSTRALIAN CRETACEOUS MICROPLANKTON

Description: Shell elongate, somewhat flat, divided approximately equally by a shallow, circular girdle, the borders of which form re-entrant angles on both sides. The middle portion of the shell, which is almost entirely filled with a large capsule, is widest at the girdle, narrowing from thence, rather abruptly, both proximally and distally. Above the upper limit of the capsule the shell again bulges prominently before terminating in a short, broad, bluntly pointed horn. The distal portion of the shell, i.e., the portion below the lower limit of the capsule, is straight-sided, truncate, and prolonged on one side into a short pointed horn. The shell-membrane is rather sparsely, finely to coarsely granular. The capsular membrane is more finely and closely granular. The pylome is circular to hoof-shaped.

Dimensions: Holotype: 100 μ long; 59 μ broad; capsule 48 \times 48 μ ; pylome 22 \times 22 μ . Other examples: 120 μ \times 71 μ , capsule 60 μ ; 109 μ \times 62 μ , capsule 58 \times 58 μ .

Deflandrea micracantha Cookson and Eisenack,
new species
Plate 1, figure 9

Holotype: Nat. Mus. Vic. no. P17796.

Age and occurrence: Campanian: Brickhouse Bore, at 455, 595 and 715 ft.

Description: Shell elongate, flat, equally divided by a rather broad and slightly helicoid girdle, epitheca and hypotheca narrowing toward the apex and antapex, respectively. The epitheca terminates in a broad, bluntly pointed, triangular horn, the hypotheca in two broad and bluntly pointed horns of unequal size. A longitudinal furrow, bordered by divergent ledges, is situated on the ventral surface of the hypotheca. A faint indication of tabulation is present. The capsule is circular in outline and fills the shell laterally. The shell membrane is closely spinulose in the capsular region, becoming more sparsely so toward both apex and antapex. The membrane of the capsule is finely granular.

Dimensions: Holotype: 133 μ long; 81 μ broad; capsule 72 \times 74 μ ; girdle 10 μ wide; diameter of pylome 30 μ . Range: 114–133 μ \times 72–87 μ .

Deflandrea macrocysta Cookson and Eisenack,
new species
Plate 1, figures 7–8

Holotype: Nat. Mus. Vic. no. P17797 (fig. 7).

Age and occurrence: Campanian: Brickhouse Bore, at 545, 595, 615, and 715 ft.

Description: Shell almost entirely filled with a large spheroidal to ovoidal capsule; shell membrane thin and delicate, usually only evident at or near the apex, where it forms a triangular horn, and at the antapex, where it extends beyond the capsule as a flat expansion (often destroyed) in which occasionally there are indications of two antapical projections. A broad, shallow girdle

divides the shell unequally, the epitheca being appreciably larger than the hypotheca. The wall of the capsule is rather thick and coarsely and densely granular. A pylome has not been observed.

Dimensions: Holotype: 94 μ long; 67 μ broad. Range: 80–109 μ \times 55–70 μ .

Genus *SCRINIODINIUM* Klement, 1957

Scriniodinium galeatum Cookson and Eisenack,
new species
Plate 1, figures 16–18

Holotype: Nat. Mus. Vic. no. P17851 (fig. 16).

Age and occurrence: Probably Cenomanian: Brickhouse Bore, at 1210 ft. Albian to Cenomanian: lower Gearle siltstone, Rough Range South no. 1 bore, core 69 (2748–2758 ft.). (?) Upper Albian – Cenomanian: north of Gingin, Wapet's seismic shot hole B1, at 210 ft.

Description: Shell about two or three times longer than broad, rather variable in outline, divided approximately equally by an ill-defined circular girdle. Central part of shell with convex sides, fully occupied by a roughly spherical capsule, the portion of the epitheca above the capsule usually straight-sided (rarely convex), gradually narrowing toward the apex, which is terminated by a short, straight horn; the portion of the hypotheca below the capsule has straight, slightly sloping sides (rarely convex) and terminates in a rounded or oblique antapex. The girdle is indicated either by re-entrant angles at the sides, by coarse, linearly arranged granules, or rarely by a few fields. A longitudinal furrow has not been observed.

The shell membrane in the region of the capsule is ornamented to varying degrees by short spines, particularly at the sides, and by spherical granules or spinules arranged in lines, usually running parallel to the length of the shell, but sometimes giving the impression of fields. In the regions beyond the capsule the shell membrane is usually unpatterned except at the apical horn, where it bears a few small granules, and at the distal limit of the hypotheca, where it is usually finely serrated. A pylome has been observed in only three of the many examples (fig. 17). It is large, trapezoidal in form, and extends from the upper limit of the capsule almost to the girdle.

Dimensions: Holotype: 90 μ long; 40 μ broad; diameter of capsule ca. 38 μ . Range: 78–110 μ long; 27–46 μ broad.

Comments: In referring this species to *Scriniodinium* we are aware that it differs in shape very considerably from that of the genotype, *Scriniodinium crystallinum* (Deflandre). However, we think it desirable that the genus should be enlarged to include shells which are extended even farther beyond the capsule than they are in *Scriniodinium luridum* (Deflandre), either anteriorly or posteriorly or in both directions, but which are without the antapical projections or horns of the genus *Deflandrea*. This we have already done (Cookson and Eisenack, 1959) in referring

COOKSON AND EISENACK

two upper Jurassic species to *Scriniodinium*, namely, *Scriniodinium ceratophorum* Cookson and Eisenack, with a prominent apical horn, and *Scriniodinium apatelum* Cookson and Eisenack, with both anterior and posterior expansions. *Scriniodinium galeatum* is distinct from *Amphidiadema denticulata* sp. nov. in the mode of opening of the capsule.

Genus *Amphidiadema* Cookson and Eisenack, new genus

Description: Shell elongate, without girdle, furrow, and horns, differentiated into a swollen middle portion containing a capsule which opens apically, and two smaller terminal portions, in the apical one of which a large dorsal pylome is developed.

Type species: *Amphidiadema denticulata* sp. nov.

Comments: This genus seems to be closely related to the genus *Deflandrea* Eisenack, especially to *Deflandrea tripartita* sp. nov., but differs from it in the absence of both apical and antapical horns. It is distinct from the genus *Scriniodinium* in the apical opening of the capsule.

Amphidiadema denticulata Cookson and Eisenack, new species

Plate 1, figure 11

Holotype: Nat. Mus. Vic. no. P17803.

Age and occurrence: Campanian: Brickhouse Bore, at 455 ft. Probably upper Turonian to middle Senonian: Gingin, Wapet's seismic shot hole B1, at 160 ft. and 170 ft.

Description: Middle portion of shell smooth, with convex sides, entirely occupied by the capsule, terminal regions cubical with granular surfaces and denticulate edges. Pylome prominent, hexagonal in outline. Capsule ovoidal, smooth-walled, opening by a terminal lid.

Dimensions: Holotype: 90 μ long; 48 μ broad. Two other examples: 57 \times 43 μ and 67 \times 43 μ .

Genus *Nelsoniella* Cookson and Eisenack, new genus

Description: Shell circular in outline, epithecal and hypothecal regions distinctly differentiated, not delimited by a girdle but by the anterior limit of the large capsule, which completely fills the hypotheca and causes the shell to bulge considerably on the ventral surface; the dorsal surface, marked by a prominent pylome, is slightly convex. The epitheca is variously sculptured and may or may not be provided with an apical horn. The wall of the hypotheca is smooth.

Nelsoniella is closely related to the genus *Deflandrea* but is readily distinguished from it by the convex form of the hypotheca, the absence of antapical horns and the fact that the capsule completely fills the cavity of the hypotheca.

Type species: *Nelsoniella aceras* sp. nov.

Nelsoniella aceras Cookson and Eisenack, new species

Plate 1, figures 12-13

- *Deflandrea cretacea* COOKSON, 1956, Australian Jour. Mar. Freshwater Res., vol. 7, p. 184, pl. 1, figs. 6-7 (Nat. Mus. Vic. nos. P16710-16711).

Holotype: Nat. Mus. Vic. no. P17798 (fig. 12).

Age and occurrence: Senonian (probably Campanian to Santonian): Toolonga calcilutite, Wapet's Rough Range South no. 1 bore, cores 56, 58-59 (2390-2447 ft.). Senonian (probably Maestrichtian to Santonian): Nelson Bore, at 5304 ft. Probably upper Turonian to middle Senonian: north of Gingin, seismic shot hole B1, at 160 ft.

Description: Shell approximately circular, somewhat longer than broad or vice versa, the extreme apex more or less deeply concave. Epitheca sparsely or densely ornamented with large granules or short wavy ridges; the thickenings are frequently arranged in two rather prominent, curved ridges which extend from base to apex. Surface of hypotheca smooth. The wall of the capsule is thin and very faintly granular. The pylome is semicircular to trapezoid.

Dimensions: Holotype: 78 μ long; 87 μ broad; pylome 28 μ \times 35 μ . Range: 64-92 μ long; 62-108 μ broad.

Nelsoniella tuberculata Cookson and Eisenack, new species

Plate 1, figure 14

Holotype: Nat. Mus. Vic. no. P17799.

Age and occurrence: Senonian (probably Campanian): Toolonga calcilutite, Wapet's Rough Range South no. 1 bore, core 56 (2390-2393 ft.). Probably upper Turonian to middle Senonian: north of Gingin, Wapet's seismic shot hole B1, at 160 ft.

Description: Shell nearly circular, epitheca with a prominent horn which arises gradually and is terminated by a small "plug" which is frequently inverted. The ornament of the epitheca is usually in the form of small tubercles or large granules, some of which are arranged in curved lines on either side of the pylome and which extend from near the base to the apex of the epitheca; in some examples the dorsal surface is unornamented. The pylome is semicircular to broadly triangular.

Dimensions: Holotype: 92 μ long; 82 μ broad; pylome 26 μ long, 34 μ broad. Range: 92-123 μ long; 82-105 μ broad; pylome 24-34 μ \times 34-47 μ .

Nelsoniella semireticulata Cookson and Eisenack, new species

Plate 1, figure 15

Holotype: Nat. Mus. Vic. no. P17800.

Age and occurrence: Probably upper Turonian to middle Senonian: north of Gingin, Wapet's seismic shot hole B1, at 120 and 160 ft.

AUSTRALIAN CRETACEOUS MICROPLANKTON

Description: Shell rather thick-walled, nearly circular in outline, with a short apical horn; epitheca ornamented on the ventral surface with a low, thin-walled reticulum which may extend to the upper portion of the hypotheca. Pylome semicircular to broadly triangular.

Dimensions: Holotype: 94 μ long; 84 μ broad; horn 12 μ ; pylome 26 \times 37 μ . Range: 86–90 μ long; 84–86 μ broad.

Genus *Ascodinium* Cookson and Eisenack, new genus

Description: Shell rather flat, oval to rhomboidal in outline, with or without apical and antapical horns and girdle, and containing an ovoidal, spheroidal, or rhomboidal capsule. Pylome formed on the dorsal surface by the detachment of a circular part of the apical region, including the apex itself, and part of the ventral wall.

Type species: *Ascodinium acrophorum* sp. nov.

Comments: The genus *Ascodinium* is obviously related to the genus *Deflandrea* but differs from it in the mode of opening the shell. In *Ascodinium* the apex is involved in the opening of both shell and capsule, whereas in *Deflandrea* the pylome is developed on the dorsal surface and typically below the apex.

Ascodinium acrophorum Cookson and Eisenack, new species

Plate 1, figures 19–20

Deflandrea acuminata COOKSON AND EISENACK, 1958, Roy. Soc. Victoria, Proc., vol. 70, p. 27, pl. 4, fig. 8.

Holotype: Nat. Mus. Vic. no P17251 (fig. 19).

Age and occurrence: (?) Upper Albian to Cenomanian: Osborne formation, Subiaco Bore, at 358 ft., and Fremantle Traffic Bridge bore no. 5, at 100 ft.

Description: Shell flat, oval to almost circular in outline, with a short, blunt apical horn and a short, pointed antapical horn situated on one side of the middle line. A rather broad girdle is clearly indicated laterally and slightly in from the margins on both surfaces. Capsule nearly spherical, sometimes slightly pointed. Shell membrane smooth except along the flatter side of the antapex, where it is faintly serrated. Wall of capsule finely granular.

Dimensions: Holotype: 72 μ long; 57 μ broad; capsule 41 \times 41 μ . Range: 62–76 μ long; 51–65 μ broad.

Ascodinium serratum Cookson and Eisenack, new species

Plate 1, figures 21–22

Holotype: Nat. Mus. Vic. no P17801 (fig. 22).

Age and occurrence: Probably Cenomanian: Brickhouse Bore, at 1210 ft. (?) Upper Albian to Cenomanian: Gingin, Wapet's seismic shot hole B1, at 190 and 200 ft.; Albian: Rough Range South no. 1 bore, core 71 (2860–2867 ft.).

Description: Shell flat, oval to circular in outline, apex without a horn, antapex truncate with a short projection on one side, girdle usually indicated by slight indentations on both sides. Capsule oval to circular in outline. Shell membrane smooth except at the antapex, where it is usually distinctly serrated. The wall of the capsule is finely granular.

Dimensions: Holotype: 63 μ long; 60 μ broad; capsule 45 \times 46 μ . Range: 57–67 μ long; 40–60 μ broad.

Ascodinium parvum (Cookson and Eisenack) new combination

Plate 1, figures 23–25

Deflandrea parva COOKSON AND EISENACK, 1958, Roy. Soc. Victoria, Proc., vol. 70, p. 28, pl. 4, figs. 12–13.

Neotype: Nat. Mus. Vic. no P17802 (fig. 23).

Age and occurrence: Probably Cenomanian: Brickhouse Bore, at 1210 ft. (?) Upper Albian to Cenomanian: Gingin, Wapet's seismic shot hole B1, at 190, 200, 210, 220, and 230 ft., Fremantle, Traffic Bridge bore no. 5, at 100 ft. Cenomanian to lower Turonian: upper Gearle siltstone, Rough Range well no. 8, at 1530–48 ft. Albian–Cenomanian and Albian: lower Gearle siltstone, Wapet's Rough Range South no. 1 bore, cores 69, 70, and 71 (2748–2867 ft.).

Description: Shell flat, more or less rhombic in outline, with a blunt or sharply pointed apex and a sharply pointed antapex; girdle equatorial and circular. Capsule large, four-sided or occasionally oval, almost filling the shell. Lid of pylome circular, but, since the whole apex is finally detached, the remaining portion of the epitheca has a truncate appearance. Shell smooth, transparent; wall of the capsule thin and smooth.

Dimensions: Neotype: 76 μ long; 55 μ broad. Emended range: 48–86 μ long; 30–56 μ broad.

Comments: Since the holotype of *Ascodinium parvum* (*Deflandrea parva*) is lost, a neotype has been substituted for it.

Family GONYAULAXIDAE Genus GONYAULAX Diesing, 1866

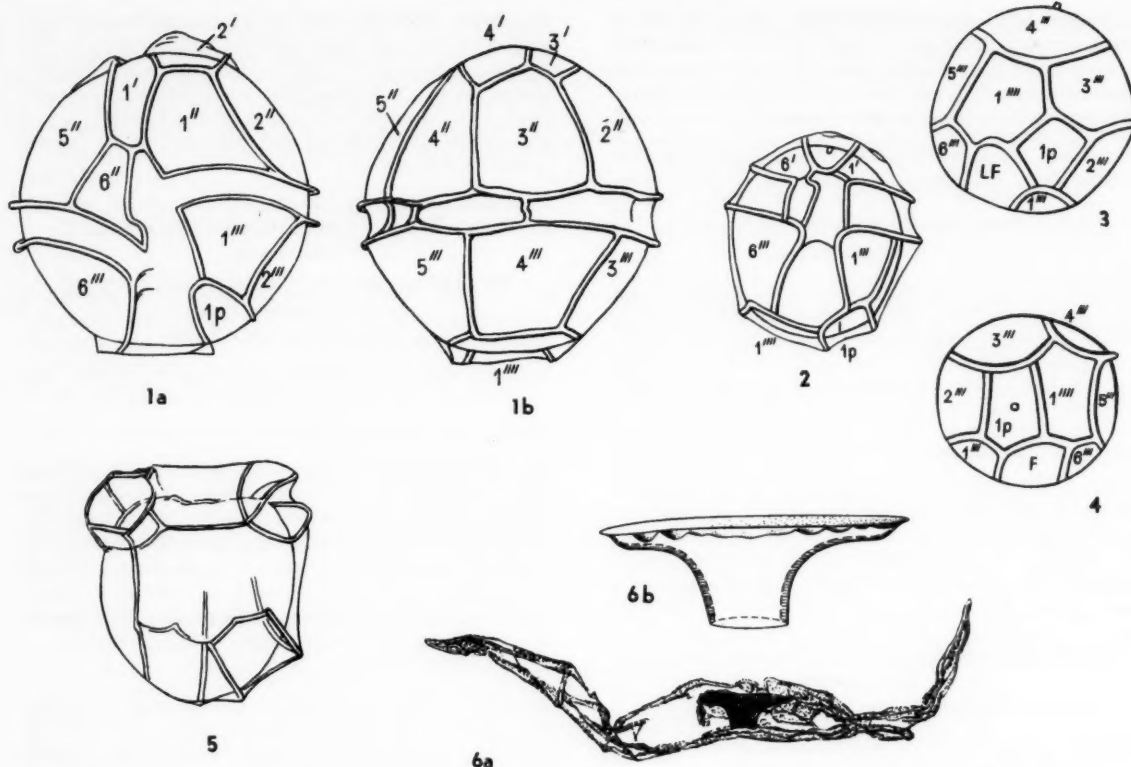
Gonyaulax margaritifera Cookson and Eisenack, new species

Plate 2, figures 1–2; text-figure 1

Holotype: Nat. Mus. Vic. no P17792 (pl. 2, fig. 1).

Age and occurrence: Senonian (probably Campanian and Santonian): Toolonga calcilutite, Rough Range South no. 1 bore, core 56 (2390–2393 ft.) and core 59 (2435–2447 ft.).

Description: Shell small, spherical to slightly oval, equally divided by a distinct helicoid girdle, epitheca and hypotheca without projections. Plates bordered by ledges, which are perforated by a single row of holes, the portions of the wall between the holes being so thickened



TEXT-FIGURES 1-6

1, *Gonyaulax margaritifera* sp. nov., \times ca. 1100: a, ventral surface; b, dorsal surface. 2-4, *Microdinium ornatum* sp. nov., \times ca. 1100: 2, ventral surface of holotype; 3-4, antapical views of two other specimens. 5, *Gillinia hymenophora* sp. nov., \times ca. 1100. 6, Gen. et sp. indet., Form A: a, complete specimen, \times ca. 200; b, main body, \times ca. 600.

that in surface view the ledges appear like strings of beads. Sometimes, in small localized areas, the ledges are higher than normal and form loop-like tufts.

The formula of tabulation is $4'$, $6''$, $1p$, $1'''$; plate $1'$ is rather long, plate $6''$ small, plate $1'''$ large. The pylome is formed by the detachment of plate $3''$.

Dimensions: Holotype: 52μ long; 49μ broad. Range: $43-52\mu \times 42-49\mu$.

INCERTAE FAMILIAE

Genus *Microdinium* Cookson and Eisenack, new genus

Description: Shell small, more or less oval in outline, with a circular girdle level with the surface, and without appendages; epitheca with one apical plate and six pre-equatorial plates; hypotheca with six post-equatorial plates, plate $1p$, and one antapical plate. The longitudinal furrow, which is level with the surface, broadens toward both apex and antapex; a few small plates may

be associated with it in the epitheca (text-figs. 2-4). The shell opens by the detachment of the apical plate.

Type species: *Microdinium ornatum* sp. nov.

Comments: *Microdinium* resembles the genus *Eisenackia* Deflandre and Cookson, 1955, but differs from it in having only one apical plate instead of two or three, and in the broadening of the longitudinal furrow toward both apex and antapex. Furthermore, the small plates associated with the longitudinal furrow are situated in the epitheca in *Microdinium* and not in the hypotheca, as in *Eisenackia*.

Microdinium ornatum Cookson and Eisenack, new species

Plate 2, figures 3-8; text-figures 2-4

Holotype: Nat. Mus. Vic. no. P17852 (pl. 2, figs. 3-4; text-fig. 2).

Age and occurrence: Albian: lower Gearle siltstone, Rough Range South no. 1 bore, cores 70-71 (2758-2867 ft.).

AUSTRALIAN CRETACEOUS MICROPLANKTON

(?) Upper Albian to Cenomanian: north of Gingin, Wapet's seismic shot hole B1, at 200, 210, and 220 ft.; Osborne formation, Subiaco Bore, at 358 ft., and Fremantle Traffic Bridge bore no. 5, at 100 ft. Probably Cenomanian: Brickhouse Bore, at 1210 ft. Cenomanian to lower Turonian: upper Gearle siltstone, Wapet's Rough Range no. 5 bore, at 1570 ft.

Description: Shell ovoidal, narrower end anterior, divided unequally by the relatively broad girdle; epitheca shorter than hypotheca. Plates bordered by low but distinct ledges, which frequently are perforated by a single row of holes and look like strings of beads in surface view. Sometimes the outer edge of the ledges may be missing, in which case the portions of the wall originally separating the perforations appear as isolated "beads." The surface of the plates may be ornamented by a varying number of small tubercles.

Dimensions: Holotype: 29 μ long; 27 μ broad. Range: 28–38 μ long; 27–36 μ broad.

Genus *Ginginodinium* Cookson and Eisenack, new genus

Description: Shell somewhat flat, with convex ventral and dorsal surfaces, a pentagonal outline, and an apical and two antapical horns and without tabulation and capsule. Girdle broad, helicoid; longitudinal furrow broad and deep, restricted to the hypotheca.

Type species: *Ginginodinium spinulosum* sp. nov.

Comments: *Ginginodinium* is distinct from *Peridinium* Ehrenberg in the absence of tabulation, and from *Deflandrea* Eisenack in the absence of a capsule.

Ginginodinium spinulosum Cookson and Eisenack, new species

Plate 2, figure 9

Holotype: Nat. Mus. Vic. no. P17804.

Age and occurrence: (?) Upper Albian to Cenomanian: Gingin, seismic shot hole B1, at 200, 210, 220, and 230 ft.

Description: Shell divided by a strongly helicoid girdle into a triangular epitheca, which tapers to a small but distinct hollow horn with a small terminal "plug," and a trapezoidal hypotheca with two hollow divergent horns of unequal size, the larger being on the right-hand side of the observer when the ventral surface is uppermost. The borders of the longitudinal furrow curve outward toward the antapical horns; the flagellum pore is sometimes evident in the longitudinal furrow. The shell membrane is densely spinulate. A clearly defined pylome is not represented, but in most specimens the dorsal wall of the epitheca is broken near the base of the horn as if forming a natural opening.

Dimensions: Holotype: 72 μ long; 64 μ broad. Range: 62–71 μ \times 54–62 μ .

Genus *Palaeohystrichophora* Deflandre, 1934

Comments: We have excluded the genus *Palaeohystrichophora* from the family Hystrichodinidae Deflandre, 1936, because the type species, *Palaeohystrichophora infusorioides*, possesses a capsule which *Hystrichodinium* Deflandre, the type genus of the family, does not.

Palaeohystrichophora infusorioides Deflandre

Palaeohystrichophora infusorioides DEFlandre, 1934, Acad. Sci., Paris, C. R., vol. 199, p. 967, text-fig. 8; 1956, Ann. Pal., vol. 25, p. 38, pl. 9, figs. 5–10.

This species, originally described from French Cenomanian and Senonian flints, has already been recorded from the upper Gearle siltstone of Western Australia (Cookson and Eisenack, 1958). It has since been found in abundance in cores 56–71 of the Rough Range South no. 1 bore, which range in age from Albian to upper Senonian; in the Campanian section (435–715 ft.) of the Brickhouse Bore, sparsely in the (?) Cenomanian at 1210 ft., and occasionally in the Molecap greensand.

Genus *Odontochitina* Deflandre, 1935

Odontochitina cribropoda Deflandre and Cookson

Odontochitina cribropoda DEFlandre and COOKSON, 1955, Australian Jour. Mar. Freshwater Res., vol. 6, p. 292, pl. 3, figs. 7–11.

Age and occurrence: Probably upper Turonian to middle Senonian: Gingin, Molecap greensand. Senonian (probably Santonian to Campanian): Toolonga calcilutite, Rough Range South no. 1 bore, cores 56 (2390–2393 ft.) and 58 (2429–2435 ft.). Senonian (probably Santonian to lower Maestrichtian): Nelson Bore, at 5782 ft.

Odontochitina porifera Cookson Plate 3, figure 9

Odontochitina porifera COOKSON, 1956, Australian Jour. Mar. Freshwater Res., vol. 7, p. 188, pl. 1, fig. 17.

Age and occurrence: Upper Turonian: upper Gearle siltstone, Rough Range South no. 1 bore, core 62 (2505–2511 ft.). Senonian (probably Santonian to Campanian): Toolonga calcilutite, Rough Range South no. 1 bore, cores 59–58 (2447–2429 ft.) and 56 (2390–2393 ft.). Probably upper Turonian to middle Senonian: north of Gingin, Wapet's seismic shot hole B1, at 160 ft. and 170 ft. Senonian (probably Santonian to lower Maestrichtian): Nelson Bore, at 6233 ft.

Comments: During the examination of a comparatively large number of specimens of *Odontochitina* with perforate horns from the Rough Range South bore, difficulty was experienced in deciding which of the two species *Odontochitina cribropoda* and *Odontochitina porifera* they represent. The difficulty arises from the difference in the shape of the horns of the figured specimens of *Odontochitina cribropoda* from the Molecap greensand from those of the holotype and other figured examples from the Nelson

Bore (Deflandre and Cookson, 1955, pl. 3, figs. 7-11). After a careful examination of all the specimens available, the conclusion has been reached that the only reasonably safe criterion for the separation of these forms is the extent to which the horns are perforated. In *Odontochitina cribropoda* only the distal portion of the horns is perforated, leaving fairly long unperforated and sometimes thick-walled proximal "stalks." In *Odontochitina* virtually the whole surface of the horns is linearly perforated. In this species, longitudinal "fibres" along which the perforations appear to develop are sometimes evident. Further investigation of these forms is desirable.

HYSTRICHOSPHERES

Order HYSTRICHOSPHAERIDEA

Family HYSTRICHOSPHAERIDAE

Genus *HYSTRICHOSPHAERIDIUM* Deflandre, 1936

Hystrichosphaeridium striatoconus

Deflandre and Cookson

Hystrichosphaeridium striatoconus DEFLANDRE AND COOKSON, 1955, Australian Jour. Mar. Freshwater Res., vol. 6, p. 275, pl. 2, fig. 10.

Age and occurrence: Probably upper Turonian to middle Senonian: Gingin, Molecap greensand. Turonian: upper Gearle siltstone, Rough Range South no. 1 bore, cores 61, 62, and 63 (2500-2514 ft.). Probably upper Turonian to middle Senonian: north of Gingin, Wapet's seismic shot hole B 1, at 160 and 170 ft.

Comments: *Hystrichosphaeridium striatoconus* was first described from the Molecap greensand. The restricted occurrence of this species in the Rough Range South sequence provides good supporting evidence that the Molecap greensand correlates with the upper Gearle siltstone and not with the lower Gearle siltstone.

Hystrichosphaeridium flosculus Deflandre

Plate 2, figure 10

Hystrichosphaeridium flosculus DEFLANDRE, 1937, Ann.Pal., vol. 26, p. 27, pl. 15, figs. 5-6.

Age and occurrence: Senonian (probably Campanian): Toolonga calcilutite, Rough Range South no. 1 bore, core 56 (2390-2393 ft.).

Comments: The form abundantly present in the Toolonga calcilutite agrees well with *Hystrichosphaeridium flosculus* from the Senonian flints of Paris and from the Molecap greensand of Western Australia (Deflandre and Cookson, 1955).

Hystrichosphaeridium ancoriferum

Cookson and Eisenack, new species

Plate 2, figure 11

Holotype: Nat. Mus. Vic. no. P17805.

Age and occurrence: Albion to Cenomanian: lower Gearle siltstone, Rough Range South no. 1 bore, core 69

(2748-2758 ft.). Albion: lower Gearle siltstone, Rough Range South no. 1 bore, cores 70-71 (2758-2758 ft.). Probably Cenomanian: Brickhouse Bore, at 1210 ft. (?) Upper Albion to Cenomanian: north of Gingin, Wapet's seismic shot hole B1, at 210 and 220 ft.; Osborne Park formation, Subiaco Bore, at 358 ft.; and Fremantle Traffic Bridge bore no. 5, at 100 ft.

Description: Shell spherical, densely covered with anchor-shaped appendages about 5-12 μ long, the stalks of which narrow distally and divide into two slender, recurved branches with transparent tips. In some examples the impression is given that the tips of the appendages are united, but usually they are free from one another.

Dimensions: Holotype: overall diameter 70 μ , diameter of shell 52 μ . Range: overall 40-70 μ ; shell 30-52 μ .

Hystrichosphaeridium heteracanthum

Deflandre and Cookson

Hystrichosphaeridium heteracanthum DEFLANDRE AND COOKSON, 1955, Australian Jour. Mar. Freshwater Res., vol. 6, p. 276, pl. 2, figs. 5-6.

Comments: *Hystrichosphaeridium heteracanthum*, which has previously been recorded from Upper Cretaceous and Lower Tertiary deposits in southeastern Australia and from the Molecap greensand of Western Australia, is relatively abundant in cores 56, 58, and 59 of the Rough Range South no. 1 bore, the age of which probably ranges from Campanian to Santonian.

Genus *CANNOSPHAEROPSIS* O. Wetzel, 1933

Cannosphaeropsis tutulosa Cookson and Eisenack, new species

Plate 2, figures 12-13

Holotype: Nat. Mus. Vic. no. P17806 (fig. 13).

Age and occurrence: Probably Cenomanian: Brickhouse Bore, at 1210 ft.

Description: Shell spherical, with numerous radial processes of equal width which divide distally and join with neighbouring branches to form the series of relatively wide and deep loops with which the shell is invested.

Dimensions: Holotype: Diameter of shell about 33 μ ; overall diameter 70 μ . Two other examples are of approximately the same size.

Cannosphaeropsis filifera (Cookson and Eisenack), new combination

Plate 2, figure 16

Cannosphaeropsis utinensis O. Wetzel, subsp. *filifera* COOKSON AND EISENACK, 1958, Proc. Roy. Soc. Vic., vol. 70, p. 46, pl. 7, fig. 4 (holotype: Nat. Mus. Vic. no. P17764).

Hypotype: Nat. Mus. Vic. no. P17856 (fig. 16).

Age and occurrence: Campanian to lower Maestrichtian: Korojon calcarenite, Wapet's Rough Range bore no. 4,

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at 1380–1386 ft. Turonian: upper Gearle siltstone, Rough Range South no. 1 bore, cores 61–63 (2500–2514 ft.).

Comments: When *Cannosphaeropsis filifera* was originally described, only one specimen of it had been found, and, although differences between it and *Cannosphaeropsis utinensis* O. Wetzel were noted, a subspecies of *Cannosphaeropsis utinensis* rather than a distinct species was established. Since then, a large number of specimens of similar form have been isolated from the upper Gearle siltstone, with characters essentially similar to those of the type. On the whole, the new examples have more flattened radial processes and rather fewer hairs than the holotype.

Dimensions: Overall diameter 100–185 μ ; diameter of shell 60–104 μ .

***Cannosphaeropsis hyperacantha* Cookson and Eisenack, new species Plate 2, figures 14–15**

Holotype: Nat. Mus. Vic. no. P17807 (fig. 14).

Age and occurrence: Senonian (probably Campanian): Toolonga calcilitite, Wapet's Rough Range South no. 1 bore, core 56 (2390–2393 ft.), and core 59 (2435–2447 ft.).

Description: Shell spherical, thin-walled, with many processes of various widths, which by their division form a dense enveloping network, the threads of which are well covered with straight or curved spines, sometimes with confluent bases. The shell as a whole has the appearance of a ball wrapped in a tangle of barbed wire.

Dimensions: Holotype: diameter of shell about 46 μ ; overall diameter about 90 μ . Range: overall diameter about 62–100 μ .

Genus *Aiora* Cookson and Eisenack, new genus

Description: Shell spherical, near the equator bearing a whorl of from five to approximately ten solid, radiating, branched processes which unite distally to form a continuous narrow and flat perforate expansion of uneven width. The resultant "float" is in the shape of a flat cone.

Type species: *Aiora fenestrata* (Deflandre and Cookson) = *Cannosphaeropsis fenestrata* Deflandre and Cookson, 1955.

Comments: The genus *Aiora* is distinct from the genus *Cannosphaeropsis* O. Wetzel, which it superficially resembles, in that the shell is not enclosed in an external network.

***Aiora fenestrata* (Deflandre and Cookson) Plate 2, figures 17–18**

Cannosphaeropsis fenestrata DEFlandre and COOKSON, 1955, Australian Jour. Mar. Freshwater Res., vol. 6, p. 283, pl. 3, fig. 2.

Hypotype: Nat. Mus. Vic. no. P17808 (fig. 17).

Age and occurrence: Probably upper Turonian to middle Senonian: Gingin Molecap greensand. Turonian: upper Gearle siltstone, Rough Range South no. 1 bore, cores 61–62 (2500–2511 ft.).

Comments: A comparison of the large number of well preserved examples of *Aiora fenestrata* recovered from the Rough Range South cores with the single specimen from the Molecap greensand described by Deflandre and Cookson has shown that the latter specimen does not belong to the genus *Cannosphaeropsis* but has the characters of the new genus *Aiora*. The marked difference between the Molecap specimen and other species of *Cannosphaeropsis* was noted in the original description.

Dimensions: Rough Range South specimens: shell about 50–80 μ ; overall diameter about 120–160 μ .

Family PTerospermopsidae Genus *Cymatiosphaera* O. Wetzel, 1933, emend. Deflandre, 1954

***Cymatiosphaera radiata* O. Wetzel Plate 2, figures 21–22**

Cymatiosphaera radiata O. WETZEL, 1933, Palaeontographica, ser. A, vol. 77, p. 29, pl. 4, fig. 8.

Age and occurrence: Albian: lower Gearle siltstone, Rough Range South no. 1 bore, cores 70–71 (2758–2867 ft.). (?) Upper Albian to Cenomanian: north of Gingin, seismic shot hole B1, at 200 and 220 ft.; Osborne formation, Subiaco Bore, at 358 ft.; and Fremantle Traffic Bridge bore no. 5, at 100 ft. Probably Cenomanian: Brick-house bore, at 1210 ft.

Description: Shell spherical, with a number of fields delimited by thin, relatively high (about 6–8 μ) perpendicular membranes supported by rather stout, evenly spaced radial processes, which bifurcate distally.

Dimensions: Overall diameter 30–43 μ ; diameter of shell about 19–26 μ .

Comments: After an examination of the holotype of *Cymatiosphaera radiata*, from a north German Senomanian flint, kindly lent to us by Dr. O. Wetzel, we have come to the conclusion that, when allowance is made for the difference in mode of preservation, the Australian specimens can safely be referred to this species.

INCERTAE SEDIS

***Actinotheca aphroditae* Cookson and Eisenack, new species Plate 2, figures 19–20**

Holotype: Nat. Mus. Vic. no. P17855 (fig. 20).

Age and occurrence: Turonian: lower Gearle siltstone, Wapet's Rough Range South no. 1 bore, cores 61–63 (2500–2514 ft.).

Description: Shell roughly circular in outline, consisting of a flat, somewhat hexagonal, box-like body and a

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broad transparent two-layered wing. The wing is supported by a series of fibres, consisting of five pairs of evenly spaced fibres that run radially to the circumference of the wing, where they join and form loops; two sets of fibres that are connected with the radial fibres and run tangentially slightly within the outer edges of the anterior and posterior surfaces of the body, where they form a hexagonal pattern; and a group of three or four pairs of fibres that form a cluster or loose tangle of loops on one side (probably ventral) of the shell. There is some evidence that the body of the shell opens by the detachment of a circular portion of the anterior wall.

Dimensions: Holotype: diameter of shell 85μ ; diameter of body 42μ . Range: diameter of shell 80 – 120μ .

Genus *CHLAMYDOPHORELLA* Cookson and Eisenack, 1958

Chlamydophorella urna Cookson and Eisenack, new species Plate 3, figure 7

Holotype: Nat. Mus. Vic. no. P17809.

Age and occurrence: Cenomanian: upper Gearle siltstone, Rough Range South no. 1 bore, core 68 (2717–2725 ft.). Albian: lower Gearle siltstone, Rough Range South no. 1 bore, cores 70 and 71 (2758–2867 ft.). (?) Upper Albian to Cenomanian: Osborne formation, Subiaco Bore, at 358 ft.; and Fremantle Traffic Bridge bore no. 5, at 100 ft.; north of Gingin, Wapet's seismic shot hole B1, at 210 and 220 ft.

Description: Shell small, oval to slightly angular in outline, appendages which support the thin external membrane extremely short and densely arranged. A "girdle" is evident, particularly at the sides of the shell. The shell opens by an uneven break at one end.

Dimensions: Holotype: 39μ long; 30μ broad. Range: 29 – 43μ long \times 24 – 38μ .

Comments: *Chlamydophorella urna* is distinct from *Chlamydophorella nyei* Cookson and Eisenack in the smaller size of both the shell and appendages and the absence of an apical projection.

Genus *Cirrifera* Cookson and Eisenack, new genus

Description: Shell elongate, with anterior and posterior horns, an oval capsule, and an ornament of straight or curved processes.

Type species: *Cirrifera unilateralis* sp. nov.

Cirrifera unilateralis Cookson and Eisenack, new species Plate 3, figure 8

Holotype: Nat. Mus. Vic. no. P17810.

Age and occurrence: (?) Upper Albian to Cenomanian: Gingin, Wapet's seismic shot hole B1, at 200 and 210 ft., Osborne formation, Subiaco Bore, at 358 ft.

Description: Shell somewhat asymmetrical, with convex sides and horns of slightly unequal length and breadth, ornamented on one side of the body and sometimes at the base of one horn by short, clavate, straight or curved, simple or slightly branched processes. Capsule cylindrical with rounded ends, rarely filling the cavity of the shell. Shell membrane thin and faintly granular; wall of capsule thin and smooth.

Dimensions: Holotype: overall length 76μ ; breadth 28μ ; capsule $30 \times 17\mu$. Range: length 60 – 86μ ; breadth 20 – 28μ ; capsule 29 – $33\mu \times 10$ – 17μ .

Genus *Diplofusa* Cookson and Eisenack, new genus

Description: Shell fusiform, containing an elongate capsule with narrow apical and antapical prolongations.

Type species: *Diplofusa gearlensis* sp. nov.

Comments: The genus *Diplofusa* is distinct from the genus *Korojonia* Cookson and Eisenack 1958, in the shape of both shell and capsule.

Diplofusa gearlensis Cookson and Eisenack, new species Plate 3, figure 10

Holotype: Nat. Mus. Vic. no. P17812.

Age and occurrence: Cenomanian: upper Gearle siltstone, Wapet's Rough Range South no. 1 bore, core 68 (2717–2715 ft.).

Description: Shell gradually tapering toward rounded apices, almost entirely filled with a large elongate-oval capsule, the approximately equal, bluntly pointed prolongations of which reach the proximal and distal limits of the shell. Shell membrane smooth, transparent and delicate. Wall of capsule firm and smooth. A pylome has not been observed.

Dimensions: Holotype: 119μ long; 34μ wide. Two other examples $121 \times 33\mu$ and $113 \times 28\mu$.

Genus *DIPLOTESTA* Cookson and Eisenack, 1959

Diplotesta luna Cookson and Eisenack, new species Plate 3, figure 21

Holotype: Nat. Mus. Vic. no. P17849.

Age and occurrence: (?) Upper Albian to Cenomanian: Gingin, Wapet's seismic shot hole B1, at 210 ft.; Osborne formation, Subiaco Bore, at 358 ft.

Description: Shell half-moon shaped, tapering toward the two bluntly pointed ends and containing a slightly concavo-convex elongate capsule which narrows distally

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toward somewhat pointed apices. Wall of both shell and capsule smooth.

Dimensions: Holotype: distance between the two apices 70 μ ; width of shell 30 μ ; capsule 54 \times 20 μ .

Comments: Six examples have been found, all of which are imperfect. However, they seem to constitute a species which is distinct from the upper Jurassic — Lower Cretaceous species *Diplotesta glaessneri* Cookson and Eisenack, 1959, in the more deeply concavo-convex outline and the more pointed apices of the shell.

Genus *Trigonopyxis* Cookson and Eisenack, new genus

Description: Shell flat, triangular in outline, partially filled with a capsule.

Type species: *Trigonopyxis ginella* sp. nov.

Trigonopyxis ginella Cookson and Eisenack, new species Plate 3, figure 18–20

Holotype: Nat. Mus. Vic. no. P17813 (fig. 19).

Age and occurrence: (?) Upper Albian to Cenomanian: north of Gingin, Wapet's seismic shot hole at 200, 210, and 220 ft.

Description: Shell triangular, with straight to concave sides and rounded angles. Capsule almost circular to broadly triangular. Shell membrane and wall of capsule smooth.

Dimensions: Holotype: shell about 50 μ ; capsule about 30 μ . Range: shell 50–66 μ ; capsule 30–43 μ .

Comments: The foregoing new genera *Cirrifera*, *Diplofusa*, and *Trigonopyxis*, together with the genera *Diplotesta* and *Korojonia* Cookson and Eisenack, are morphologically similar in that their shells are without tabulation and girdle and contain a capsule. We therefore suggest that, in future, they be grouped together in one family, to be known as the Diplotestidae.

Genus *Codonia* Cookson and Eisenack, new genus

Description: Shell spherical to oval, with two opposite hollow, equatorial projections open to the exterior, the delicate membrane of which is supported by fibrous loops.

Type species: *Codonia campanulata* sp. nov.

Codonia campanulata Cookson and Eisenack, new species Plate 3, figures 1–3

Holotype: Nat. Mus. Vic. no. P17811 (fig. 1).

Age and occurrence: Senonian (probably Santonian): Toolonga calcilutite, Rough Range South no. 1 bore, core 59 (2435–2447 ft.). Turonian: upper Gearle siltstone,

Rough Range South no. 1 bore, core 62 (2505–2511 ft.) and core 66 (2660–2665 ft.). Probably upper Turonian to middle Senonian: Gingin, Molecap greensand. Cenomanian: upper Gearle siltstone, Rough Range South no. 1 bore, core 68 (2717–2725 ft.).

Description: Shell approximately spherical, with a short truncate neck (in the type) and two relatively large campanulate or trumpet-shaped projections. The wall of the projections is thin and transparent, and strengthened by clearly defined fibrous loops which widen distally. The projections appear to be connected with one another and with the surface of the shell by a membrane which extends tangentially between their anterior and posterior limits.

Dimensions: Holotype: overall length 128 μ ; diameter of shell about 46 μ ; projections 45 μ and 38 μ long, 58 μ and 46 μ wide. Range: overall length 120–128 μ .

Genus *Disphaeria* Cookson and Eisenack, new genus

Description: Shell approximately three-quarters of a sphere, with a large circular opening and a partially enclosed capsule.

Type species: *Disphaeria macropyla* sp. nov.

Disphaeria macropyla Cookson and Eisenack, new species Plate 3, figures 13–14

Holotype: Nat. Mus. Vic. no. P17854 (fig. 13).

Age and occurrence: Turonian: upper Gearle siltstone, Wapet's Rough Range South no. 1 bore, cores 61, 62, 63 (2500–2514 ft.) (abundant). Probably upper Turonian to middle Senonian: Molecap greensand (one specimen).

Description: Shell membranous, thin-walled, usually compressed, smooth or with a few short scattered spinules. Capsule roughly spherical, wall thin, usually with scattered spinules, especially on the posterior surface. In two specimens very fine threads can be seen passing from both sides of the equatorial region of the capsule to the shell-membrane, but whether or not they form part of the structure by which the capsule is suspended in the shell is not clear.

Dimensions: Holotype: diameter of shell 80 μ ; diameter of capsule 40 μ ; aperture of shell 50 μ . Range: diameter of shell 67–88 μ ; diameter of capsule 38–50 μ .

Genus *Gillinia* Cookson and Eisenack, new genus

Description: Shell circular to oval in outline, bearing fine surface ridges which partly or wholly delimit fields of varying shape and size and form two more or less spherical hollow membranous structures with a net-like appearance on either side of the anterior surface.

Type species: Gillinia hymenophora sp. nov.

The generic name is given in honour of Mr. E. D. Gill of the National Museum of Victoria.

***Gillinia hymenophora* Cookson and Eisenack,
new species**

Plate 3, figures 4–6; text-figure 5

Holotype: Nat. Mus. Vic. no. P17814 (fig. 4).

Age and occurrence: Senonian (Campanian to Maestrichtian): Korojon calcarenite, Wapet's Rough Range bore no. 4, 1380–1386 ft. Senonian (probably Campanian): Toolonga calcilutite, Wapet's Rough Range South no. 1 bore, core 56 (2390–2393 ft.). Probably upper Turonian to middle Senonian: Molecap greensand, north of Gingin, Wapet's seismic shot hole B1, at 120, 160, and 170 ft.

Description: Shell somewhat flat, circular to oval in outline; shell membrane two-layered, inner layer smooth, about 1μ thick, outer layer transparent, raised into low ridges which outline complete or incomplete fields, the long axes of which lie parallel to the length of the shell, and two small, spherical or low funnel-shaped membranous structures on either side of the anterior surface. The latter structures are variously connected tangentially, either by fibrous strands or by reticulate membranes; it is possible that they are open distally, but this point has not been satisfactorily determined.

Dimensions: Holotype: 38μ long; 33μ broad. Range: 25–51 μ long; 23–33 μ broad.

Genus PALAEOSTOMOCYSTIS Deflandre, 1935

***Palaeostomocystis apiculata* Cookson and Eisenack,
new species**

Plate 3, figure 15

Holotype: Nat. Mus. Vic. no. P17853.

Age and occurrence: Campanian: Brickhouse Bore, at 435 and 455 ft. Probably Santonian: Toolonga calcilutite, Rough Range South no. 1 bore, core 59 (2435–2447 ft.); north of Gingin, Wapet's seismic shot hole B1, at 120 ft.

Description: Shell ellipsoidal, straight or with one side more strongly convex than the other, narrowing toward the slightly sunken aperture. Shell membrane thin, slightly thickened around the aperture, usually with sparsely distributed spinules in the anterior and posterior regions.

Dimensions: Holotype: 62μ long, 35μ broad. Range: 38–62 μ \times 19–35 μ .

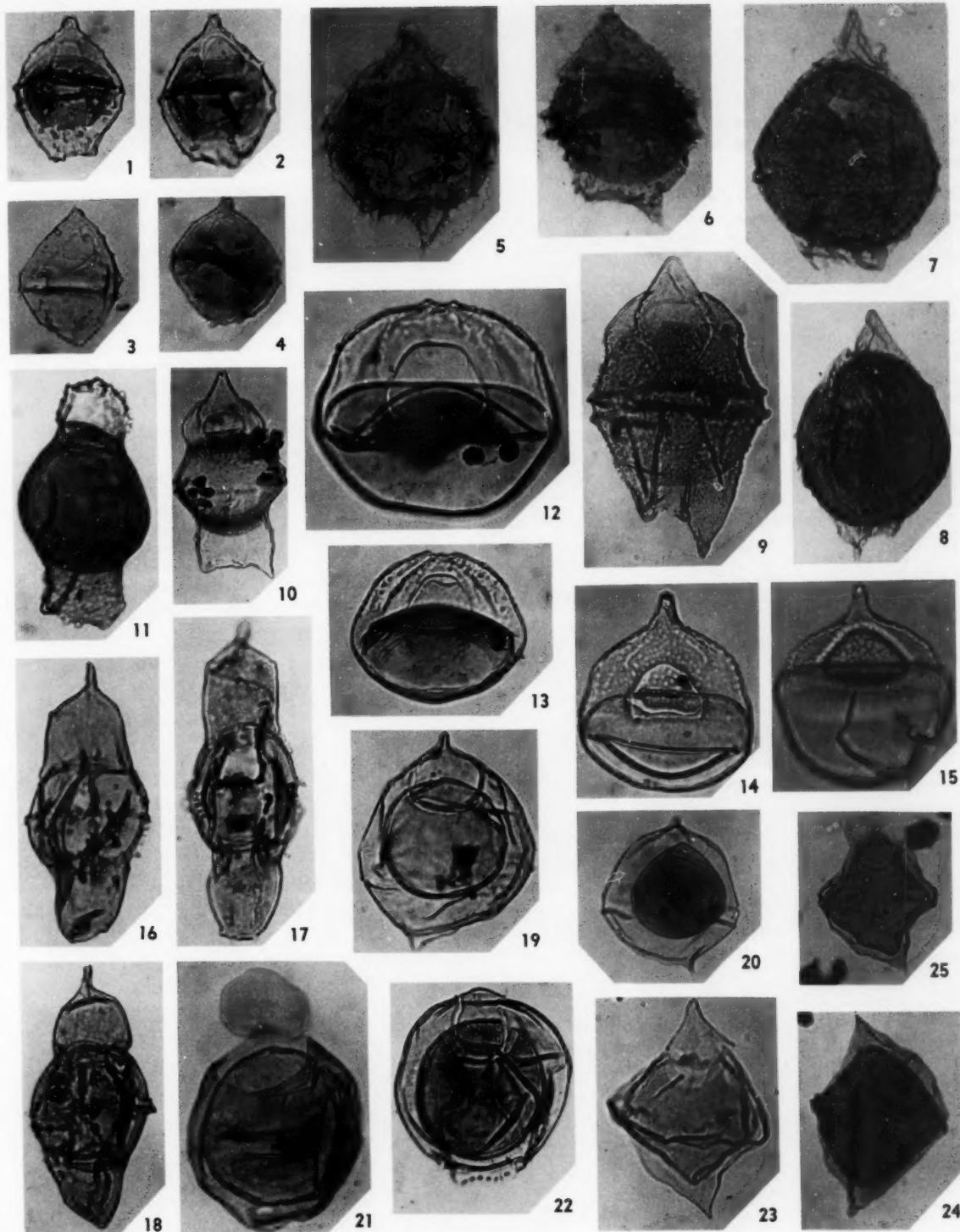
***Platycystidia* Cookson and Eisenack,
new genus**

Description: Shell more or less flat, containing a central narrow, elongate capsule, the long axis of which lies in the anteroposterior plane. Membrane of the shell appearing as two wing-like expansions.

Type species: Platycystidia diptera sp. nov.

PLATE 1

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| <p>1–4 <i>Deflandrea minor</i> sp. nov.
Rough Range South no. 1 bore, at 2505–2511 ft.;
\times ca. 500.</p> <p>5–6 <i>Deflandrea echinoidea</i> sp. nov.
Rough Range South no. 1 bore: 5, at 2390–2393 ft.; 6, at 2435–2447 ft.; \times ca. 500.</p> <p>7–8 <i>Deflandrea macrocysta</i> sp. nov.
Brickhouse Bore, at 595 ft.: 7, \times ca. 500;
8, \times 400.</p> <p>9 <i>Deflandrea micracantha</i> sp. nov.
Brickhouse Bore, at 615 ft.; \times ca. 400.</p> <p>10 <i>Deflandrea tripartita</i> sp. nov.
North of Gingin, seismic shot hole, at 160 ft.;
\times ca. 400.</p> <p>11 <i>Amphidiadema denticulata</i> sp. nov.
Brickhouse Bore, at 455 ft.; \times ca. 550.</p> <p>12–13 <i>Nelsoniella aceras</i> sp. nov.
Rough Range South no. 1 bore, at 2435–2447 ft.;
12, \times ca. 500; 13, \times ca. 400.</p> | <p>14 <i>Nelsoniella tuberculata</i> sp. nov.
Rough Range South no. 1 bore, at 2390–2393 ft.;
\times ca. 400.</p> <p>15 <i>Nelsoniella semireticulata</i> sp. nov.
North of Gingin, seismic shot hole B1, at 160 ft.;
\times ca. 400.</p> <p>16–18 <i>Scriniodinium galeatum</i> sp. nov.
Brickhouse Bore, at 1210 ft.: 16–17, \times 550; 18,
\times ca. 580.</p> <p>19–20 <i>Ascodinium acrophorum</i> sp. nov.
Subiaco Bore, at 358 ft.: 19, \times ca. 550; 20,
\times ca. 300.</p> <p>21–22 <i>Ascodinium serratum</i> sp. nov.
21, Rough Range South no. 1 bore, at 2860–2867
ft., \times ca. 530; 22, Brickhouse Bore, at 1210 ft.,
\times ca. 550.</p> <p>23, 25 <i>Ascodinium parvum</i> (Cookson and Eisenack)
Fremantle Traffic Bridge Bore, at 100 ft.: 23,
\times ca. 500; 25, \times ca. 400.</p> <p>24 <i>Ascodinium parvum</i> (Cookson and Eisenack)
Rough Range South no. 1 bore, at 2860–2867 ft.;
\times ca. 500.</p> |
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COOKSON AND EISENACK

Platycystidia diptera Cookson and Eisenack, new species

Plate 3, figure 22

Holotype: Nat. Mus. Vic. no. P17815.

Age and occurrence: (?) Upper Albian to Cenomanian: north of Gingin, Wapet's seismic shot hole B1, at 210 and 220 ft.

Description: Shell four-sided, slightly longer than broad, with rounded angles, more or less undulate margins, and a short triangular "horn" situated to one side of the middle line. Capsule ellipsoidal, with rounded ends and a tiny beak at the anterior end, adjacent to the side of the apical "horn" where the opening of the shell takes place. Membrane of the shell smooth, very finely toothed at the margins and with a few granules on the surface of the "horn." Delicate lines can usually be seen in the membrane, extending on both sides from the region of the capsule about halfway to the margin.

Dimensions: *Holotype*: overall length 48 μ ; breadth about 30 μ ; capsule 38 \times 11 μ . Range: 38–48 μ long; 28–33 μ broad; capsule 29–40 μ \times 10–17 μ .

Genus *Toolongia* Cookson and Eisenack, new genus

Description: Shell hemispherical, circular to oval in outline; shell membrane thin, raised on the "upper" sur-

face into a number of radiating ledges, some of which join and form distinct fields.

Type species: *Toolongia medusoides* sp. nov.

Toolongia medusoides Cookson and Eisenack, new species

Plate 3, figure 11–12

Holotype: Nat. Mus. Vic. no. P17816 (fig. 11).

Age and occurrence: Senonian (probably Campanian and Santonian): Toolongia calcilutite, Rough Range South no. 1 bore, core 56 (2390–2393 ft.) and core 59 (2435–2447 ft.).

Description: Shell flat, almost circular in outline, with a scalloped edge. Shell membrane thin and smooth, showing indications of two or three concentric zones, the outermost and narrowest of which follows the pointed distal outlines of the ledges. Ledges high, sometimes forming distinct fields, gradually lowering distally.

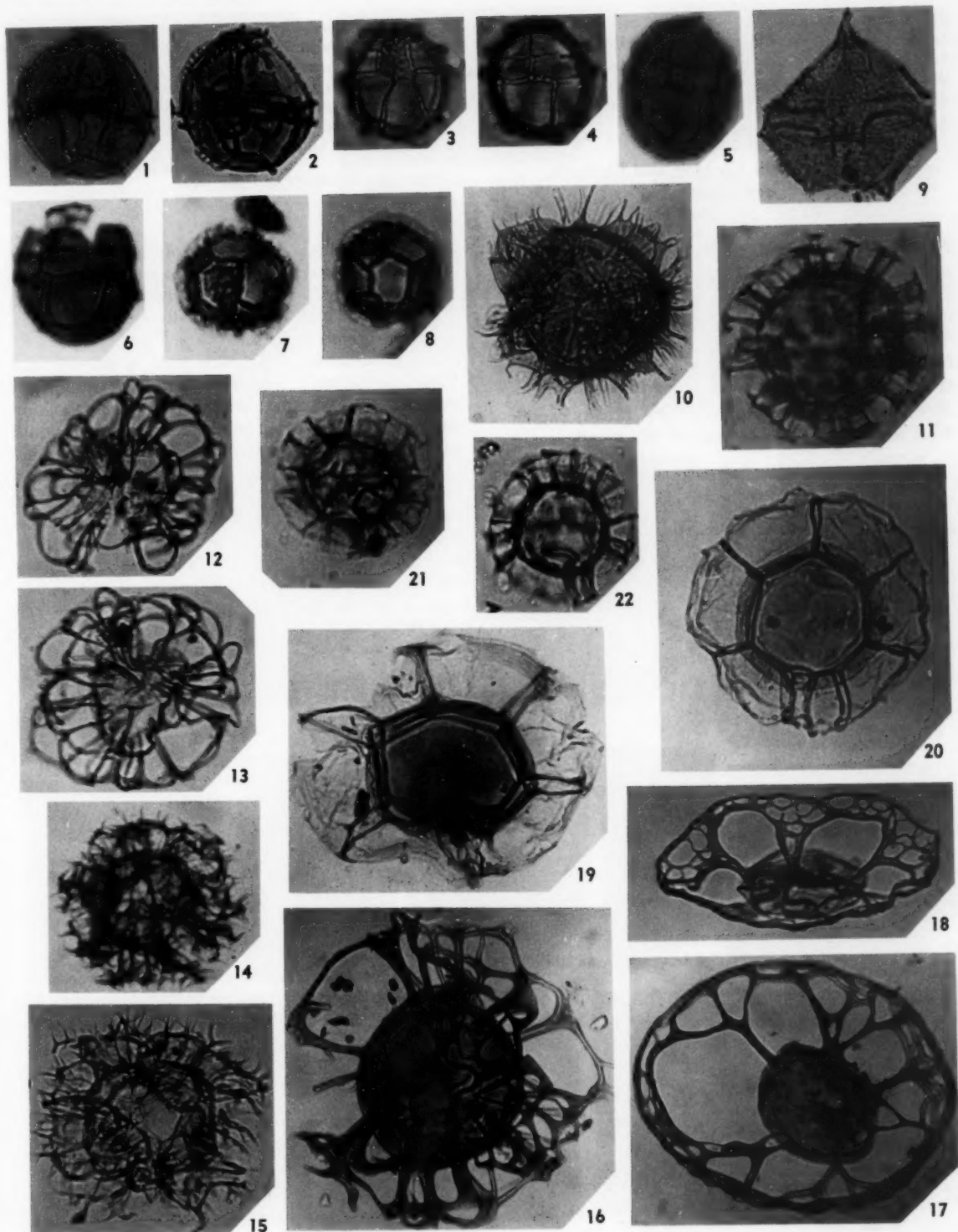
Dimensions: *Holotype*: overall diameter 90 \times 100 μ . Range: overall diameter about 80–120 μ .

Genus *Xenikoon* Cookson and Eisenack, new genus

Description: Shell ovoidal, slightly pointed anteriorly, containing a spherical capsule, the wall of which is in

PLATE 2

- 1–2 *Gonyaulax margaritifera* sp. nov.
Rough Range South no. 1 bore, at 2390–2393 ft.:
1, \times ca. 550; 2, \times ca. 500.
- 3–4 *Microdinium ornatum* sp. nov.
Ventral and dorsal surfaces of holotype; Fremantle Traffic Bridge Bore no. 5, at 100 ft.;
 \times ca. 800.
- 5–6 *Microdinium ornatum* sp. nov.
North of Gingin, seismic shot hole B1, at 220 ft.:
5, showing partial detachment of apical plate;
both \times ca. 800.
- 7–8 *Microdinium ornatum* sp. nov.
North of Gingin, seismic shot hole B1, at 210 ft.;
apical view of two specimens: 7, showing partial
detachment of apical plate; 8, the complete
apical opening; \times ca. 700.
- 9 *Gingiodinium spinulosum* sp. nov.
North of Gingin, seismic shot hole B1, at 210 ft.;
 \times ca. 550.
- 10 *Hystichosphaeridium flosculus* Deflandre
Rough Range South no. 1 bore, at 2390–2393 ft.;
 \times ca. 500.
- 11 *Hystichosphaeridium ancoriferum* sp. nov.
Rough Range South no. 1 bore, at 2860–2867 ft.;
 \times ca. 550.
- 12–13 *Cannosphaeropsis tutulosa* sp. nov.
Brickhouse Bore, at 1210 ft.; \times ca. 550.
- 14–15 *Cannosphaeropsis hyperacantha* sp. nov.
Rough Range South no. 1 bore, at 2390–2393 ft.;
 \times ca. 500.
- 16 *Cannosphaeropsis filifera* Cookson and Eisenack
Rough Range South no. 1 bore, at 2511–2514 ft.;
 \times ca. 400.
- 17–18 *Aiora fenestrata* (Deflandre and Cookson)
Rough Range South no. 1 bore, at 2505–2511 ft.;
17, hypotype, \times ca. 400; 18, \times ca. 350.
- 19–20 *Actinotheca aphroditae* sp. nov.
Rough Range South no. 1 bore, at 2505–2511 ft.;
 \times ca. 530.
- 21–22 *Cymatiosphaera radiata* O. Wetzel
Rough Range South no. 1 bore, at 2860–2867 ft.:
21, \times ca. 700; 22, \times ca. 900.



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direct contact with the wall of the shell except at the anterior end. A pylome is present shortly below the apex. In one example, which unfortunately is damaged, the shell seems to have been enclosed in a smooth outer membrane (plate 3, fig. 17).

Type species: Xenikoon australis sp. nov.

Xenikoon australis Cookson and Eisenack, new species

Plate 3, figures 16-17

Holotype: Nat. Mus. Vic. no. P17850 (fig. 17).

Age and occurrence: Campanian: Brickhouse Bore, at 715 ft. Probably upper Turonian to middle Senonian: north of Gingin, Wapet's seismic shot hole B1, at 120 and 170 ft.

Description: Characters of the genus. Shell membrane granular, pylome semicircular to nearly square.

Dimensions: Holotype: 59 μ long; 47 μ broad; capsule 47 \times 52 μ . Range: 50-70 μ long; 43-62 μ broad.

Genus and species indeterminate, Form A Text-figure 6

Figured specimen: Nat. Mus. Vic. no. P17856.

Age and occurrence: Turonian: upper Gearle siltstone, Rough Range South no. 1 bore, core 62 (2505-2511 ft.). Probably upper Turonian to middle Senonian: Molecap greensand.

Description: Main body (as far as preserved) rather thick-walled, hollow and funnel-shaped with strongly concave sides and a truncate end. The flat "upper" surface has a sharp rim with small depressions around its circumference, which give it an undulate appearance. The body is enclosed in an extensive thin, transparent membrane, which seems to be attached to the rim.

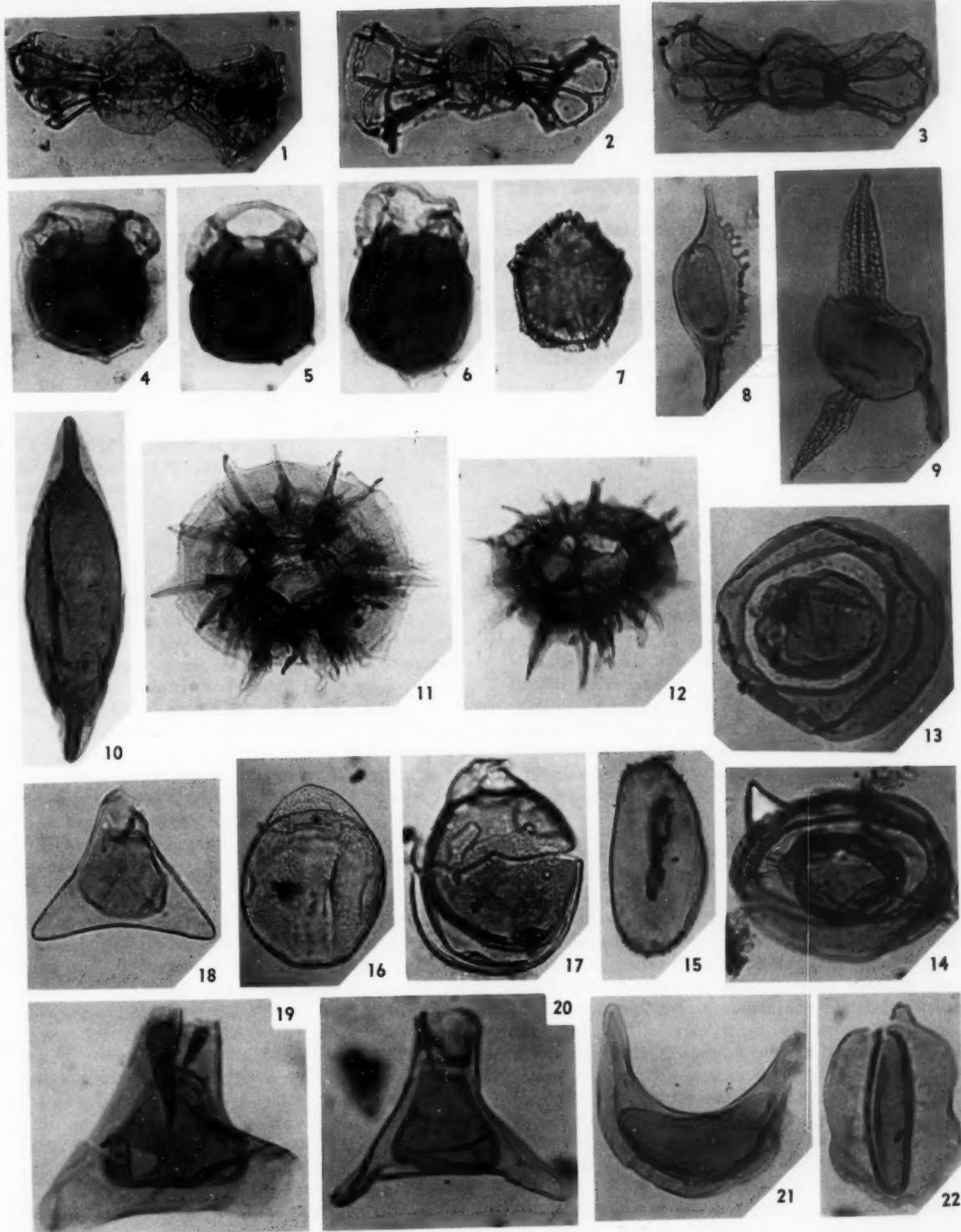
Dimensions: Diameter of body 80 μ .

CONCLUSIONS

The present investigation definitely confirms the opinion expressed earlier by Deflandre and Cookson (1955) and by Cookson and Eisenack (1958 and 1959) that, whilst some Australian microplankton have a relatively long time-range (eg. *Palaeohystrichophora infusorioides* Deflandre and some of the Hystrichospheres), others have a strictly limited vertical distribution. When the microplankton assemblages intersected by the Rough Range South no. 1 bore are considered as a whole, it becomes clearly evident that those present in the Toolonga calcilutite, upper Gearle siltstone, and lower Gearle siltstone are quite distinct from one another. Similarly, the assemblage occurring in the Brickhouse Bore between 435 and 715 ft. is distinct from that at 1210 ft. The detailed stratigraphic implications arising from this work will be considered in a subsequent paper.

PLATE 3

- | | |
|---|---|
| <p>1-3 <i>Codonia campanulata</i> sp. nov.
Rough Range South no. 1 bore, at 2660-2665 ft.;
\times ca. 400.</p> <p>4-6 <i>Gillinia hymenophora</i> sp. nov.
Rough Range South no. 1 bore, at 2390-2393 ft.;
\times ca. 800.</p> <p>7 <i>Chlamydophorella urna</i> sp. nov.
Fremantle Traffic Bridge bore no. 5, at 100 ft.;
\times ca. 680.</p> <p>8 <i>Cirrifera unilateralis</i> sp. nov.
North of Gingin, seismic shot hole, at 210 ft.;
\times ca. 550.</p> <p>9 <i>Odontochitina porifera</i> Cookson
North of Gingin, seismic shot hole B1, at 160 ft.;
\times ca. 260.</p> <p>10 <i>Diplofusa gearlensis</i> sp. nov.
Rough Range South no. 1 bore, at 2717-2725 ft.;
\times ca. 540.</p> | <p>11-12 <i>Toolongia medusoides</i> sp. nov.
Rough Range South no. 1 bore, at 1390-1393 ft.:
11, \times ca. 600; 12, \times ca. 380.</p> <p>13-14 <i>Disphaeria macropyla</i> sp. nov.
Rough Range South no. 1 bore, at 2505-2511 ft.:
13, \times ca. 500; 14, \times ca. 550.</p> <p>15 <i>Palaeostomocystis apiculata</i> sp. nov.
Brickhouse Bore, at 435 ft.; \times ca. 600.</p> <p>16-17 <i>Xenikoon australis</i> sp. nov.
Brickhouse Bore, at 715 ft.; both \times ca. 600; 17,
showing association with an outer layer.</p> <p>18-20 <i>Trigonopyxis ginella</i> sp. nov.
North of Gingin, seismic shot hole B1: 19, at
220 ft., \times ca. 670; 18, 20, at 210 ft., \times ca. 550.</p> <p>21 <i>Diplofusa luna</i> sp. nov.
North of Gingin, seismic shot hole B1, at 210 ft.;
\times ca. 550.</p> <p>22 <i>Platycystidia diptera</i> sp. nov.
North of Gingin, seismic shot hole B1, at 210 ft.;
\times ca. 800.</p> |
|---|---|



COOKSON AND EISENACK

ACKNOWLEDGMENTS

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ABSTRACT: The taxonomy, morphology and affinities of the subfamily Hastigerininae are discussed. Lectotypes have been designated and described for *Globigerina siphonifera* d'Orbigny and *Globigerina aequilateralis* Brady whilst a neotype has been designated for *Nonionina pelagica*, this same neotype also standing as lectotype for *Hastigerina murrayi* Thomson. The morphology of the genus *Hastigerinella* Cushman 1927 is discussed and a re-interpretation of Rhumbler's figure of the type species, *Hastigerina digitata* Rhumbler, is given, based on examination of Recent conspecific material. A new subgenus of *Globorotalia* Cushman 1927, *Globorotalia* (Beella) new subgenus, is proposed. The classification of the *Globorotaliinae* and *Hastigerininae* is revised, and the interrelationships of their genera and subgenera are re-examined in the light of the authors' previous work. The iteration of biocharacters, especially the character of digitate, radially elongate chambers, within the *Globigerinaceae*, is discussed.

The taxonomy, morphology and affinities of the genera included in the subfamily Hastigerininae

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INTRODUCTION

Banner and Blow (1959) outlined a classification of the *Globigerinaceae* in a preliminary paper and emended the subfamily *Hastigerininae*. Following further intensive work on the collections deposited in the British Museum (Natural History), London, and on the collections of Alcide d'Orbigny deposited in the Muséum National de l'Histoire Naturelle, Paris, as well as an examination of excellently preserved recent material sent to us by Dr. Allan Bé of the Lamont Geological Observatory, Palisades, New York, some interesting new facts have come to light which demand a revision of our earlier (Banner and Blow 1959) work on the *Hastigerininae*.

Whilst in Paris we examined and fixed lectotypes for many of d'Orbigny's planktonic species and these will be reported in a further publication. However, the single, and only remaining type of *Globigerina siphonifera* d'Orbigny was seen to be identical in all respects with *Globigerina aequilateralis* Brady (see text-figs. 2 and 3). Since no type was designated by Brady for his species "*aequilateralis*" this has now been done and a lectotype isolated. Also, whilst in Paris an exhaustive search was made by us under the guidance of MM. Pierre Marie, J. Sornay and M. Lys for the type of *Nonionina pelagica* but without success. However, the French workers were able to find the original samples used by d'Orbigny in which he found his species. This material was

also examined in great detail but again without success. Consequently, a neotype for *Nonionina pelagica* has been erected from a slide bearing Wyville Thomson's monogram deposited in the British Museum (Natural History). The same specimen designated by us as neotype of *Nonionina pelagica* d'Orbigny has also been designated by us as the lectotype of *Hastigerina murrayi* Thomson 1876. The above points are discussed in more detail later in this paper.

Banner and Blow (1959) originally considered *Hastigerinella* to be related to the genus *Globorotalia*, and, in fact, considered the former to be a subgenus of the latter. This was based on the definition given by Bolli, Loeblich and Tappan (1957, p. 32), which explicitly stated that the test of *Hastigerina digitata* Rhumbler, the type species of *Hastigerinella* Cushman 1927, was trochospiral and that the aperture was interiomarginal, extraumbilical-umbilical, "a broad arch, which becomes more extensive with age, extending to the periphery or even becoming spiro-umbilical." By this statement, they imply that the aperture need not necessarily extend onto the dorsal surface; in fact, Bolli's species *Hastigerinella bermudezi* clearly possesses an aperture confined to the ventral side. Furthermore, Bolli, Loeblich and Tappan (op. cit. p. 32, pl. 5, fig. 3a-b) ascribed Brady's species *Globigerina digitata* to the genus *Hastigerinella*, indicating that in their concept the genus was

trochoid and with an aperture which is interior-marginal, umbilical-extraumbilical and essentially confined to the ventral side.

Cushman (1927) in his original description of *Hastigerinella*, merely defined it as "similar to *Hastigerina* in the young, in the adult the chambers elongate, club-shaped, the spines limited to the outer ends of the chambers." Although this definition is inadequate, the results of our studies have shown that Cushman apparently correctly appreciated the relationships of the forms. It must also be remembered that Cushman (1927) used *Globigerina aequilateralis* Brady as the type species of his genus *Globigerinella*.

We agree with Bolli, Loeblich and Tappan (1957, p. 29) in regarding *Globigerinella* Cushman, 1927 as a junior synonym of *Hastigerina* Thomson, 1876. The only difference of kind between the two type species of the genera is in the nature of the spines. In *Hastigerina pelagica* (d'Orbigny) the spines are tri-radiate (see text-fig. 10) whilst in *Hastigerina siphonifera* (d'Orbigny) (= *H. aequilateralis* (Brady)) the spines appear to be slender, elongate conical rods. Since calcite crystallises in the hexagonal (trigonal) system the tri-radiate nature of the spines in *pelagica* may be due to crystallographic reasons rather than fundamental genetic causes.

Following our previous paper (Banner and Blow 1959), we had correspondence with Dr. Allan Bé of Lamont Geological Observatory, Palisades, New York, who sent us Recent specimens of *Hastigerinella rhumbleri* Galloway (*Hastigerina digitata* Rhumbler) from the Atlantic Ocean. Our examination of this material shows that *Hastigerinella digitata* (Rhumbler) is closely related to *Hastigerina pelagica* (d'Orbigny) and that its coiling mode, whilst initially approximately planispiral as in *Hastigerina pelagica*, becomes clearly streptospiral in later ontogeny; furthermore, the last few chambers develop multiple hornlike extensions. It is emphasized that *Hastigerinella digitata* (Rhumbler) is not trochospiral, as stated by Bolli, Loeblich and Tappan, who appear not to have had the advantage of seeing any type or comparative material whatsoever; they may have been misled by the presence of multiple extensions of the later chambers, which gives a confusing appearance to Rhumbler's original figure. We have written to the University of Göttingen in the hope that Rhumbler's type material might be preserved there. Dr. Georg Birukow of the Zoologisches Institut und Museum der Universität has diligently searched for it in his collection and also in the collections of the Geologisches Institut, Göttingen as well as in Forstzoologischen Institut, but without success.

In any case, the species in question is so very distinctive in its gross morphology, that there can be no doubt that the forms described here are conspecific with Rhumbler's type specimens. If it can be established that Rhumbler's type material is lost, and if no better descriptions are forthcoming from other workers, we shall propose that our hypotype of *Hastigerinella digitata* be designated neotype of the species (text-fig. 8a-c).

In our previous paper (op. cit.) we distinguished and erected primary types for the two generically different forms included by Brady (1879 and 1884) in his *Globigerina digitata*. We retained Brady's name *digitata* for the trochospirally coiled, globorotalid form, which we described as *Globorotalia* (*Hastigerinella*) *digitata* (Brady), following Bolli, Loeblich and Tappan's morphological interpretation of *Hastigerinella*. However, as that interpretation is now shown to be incorrect, we here emend the taxon *Hastigerinella* Cushman 1927, and revise that part of our key to the genera and subgenera of the Globigerinaceae which is effected by this emendation.

The authors' names are arranged alphabetically and the arrangement implies no seniority whatsoever. This paper forms part of a series, in which the taxonomy and interrelationships of the superfamily Globigerinaceae will be dealt with.

SYSTEMATICS

Family GLOBIGERINIDAE Carpenter, 1862,
emended Banner and Blow 1959

Subfamily HASTIGERININAE Bolli, Loeblich and
Tappan, 1957, emended Banner and Blow, 1959

Genus HASTIGERINA Thomson, 1876,
emended Banner and Blow, 1959

Type species: *Hastigerina murrayi* Thomson, 1872 =
Nonionina pelagica d'Orbigny, 1839

Subgenus HASTIGERINA, emended Banner and Blow,
1959

***Hastigerina* (*Hastigerina*) *pelagica* (d'Orbigny),**
emended Banner and Blow

Text-figure 1

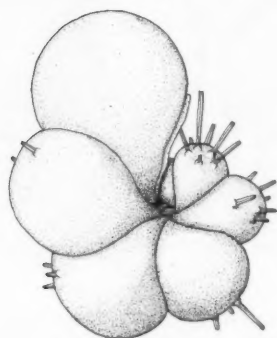
Nonionina pelagica d'ORBIGNY, 1839, "Voyage dans l'Amerique Meridionale; Foraminifères", Strasbourg; vol. 5, pt. 5, p. 27, pl. 3, figs. 13-14 (not figs. 1-2).

Lituola pelagica (d'Orbigny). - JONES and PARKER, 1860, Geol. Soc. London, Quart. Journ., London, vol. 16, p. 302, table 181.

Globigerina pelagica (d'Orbigny). - PARKER and JONES, 1865, Roy. Soc. London, Phil. Trans., vol. 155, p. 366.

Hastigerina murrayi THOMSON, 1876, Roy. Soc. London, Proc., vol. 24, p. 534, pls. 22-23 (pl. 22, lower specimen, lectotype here designated).

Hastigerina pelagica (d'Orbigny). - BRADY, 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 613, pl. 83, figs. 1-4, 6 (not figs. 7, 8); pl. 83, fig. 4 is neotype, here designated.



TEXT-FIGURE 1

Hastigerina pelagica (d'Orbigny), \times ca. 53, from Beebex Station 996, depth 0-400 fathoms; Recent, Atlantic Ocean. Hypotype, B. M. (N. H.) Catalogue No. 1959. 5.11.743. Side view, showing symmetrically but sparsely distributed trigonally-prismatic spines on the periphery, and the constancy of chamber shape and coiling mode during growth (compare text-figure 5).

Hastigerina murrayi Thomson. — BOLLI, LOEBLICH and TAPPAN, 1957, U. S. Nat. Mus. Bull. no. 215, p. 29, pl. 3, figs. 1-3b.

Hastigerina pelagica (d'Orbigny). — A.G.I.P. Mineraria, 1957, *Foraminiferi Padani*, pl. 46, figs. 10, 10p.

Hastigerina pelagica (d'Orbigny). — BÉ, 1959, *Micropaleontology*, vol. 5, no. 1, p. 83, pl. 2, figs. 21-22.

Hastigerina pelagica (d'Orbigny). — BRADSHAW, 1959, *Cush. Found. Foram. Res., Contr.*, vol. 10, pt. 2, p. 47, pl. 8, figs. 14-15.

Taxonomy: An exhaustive search by MM. P. Marie, J. Sornay, M. Lys and ourselves in the Muséum National de l'Histoire Naturelle, Paris, failed to find any type of this species. The type must now be considered lost especially since MM. P. Marie and M. Lys have been working on the d'Orbigny collections for many years and know them exceedingly well. However, the three samples, used by d'Orbigny, from the Pacific Ocean were found, their numbers being 237, 239 and 244 (numbered in black ink but now also renumbered in red ink as 258, 258¹, 258² respectively). These three samples must be considered as the only remaining topotypic material. Sample 237 consists of Pteropoda, small Crustacea, very rare *Globigerina* spp. and common *Ammonia* together with some shards of ?volcanic glass. The other samples 239 and 244 were smaller in bulk, similar in organic content but lacked the ?volcanic glass of 237. A diligent search through all these samples failed to find any form which could be possibly referred to any *Nonionina* or *Hastigerina*-like type; further, d'Orbigny mentioned in his type description of *Nonionina pelagica* that it was rare. Accordingly, since no original topotypic specimens can be found, and under the Rules of Nomenclature embodying the Copenhagen Decisions (1953), a *neotype* is here designated from the first available illus-

trated material which has been obtained from the recent oceans. The specimens obtained by the Challenger expedition were first studied by Wyville Thomson (1876) and subsequently by H.B. Brady (1884). Thomson described as new *Hastigerina murrayi*; the same specimens were subsequently studied and refigured by Brady and, following Parker and Jones, he believed them to be fully synonymous with *Nonionina pelagica* d'Orbigny; we are in full agreement with this as are also many present day workers. We consider it most unlikely that the form described by d'Orbigny should be unique and *H. murrayi* is the only known species of any genus which agrees with *N. pelagica* in morphology and occurrence. Therefore, in order to maintain the taxonomic *status quo*, we hereby designate that specimen of *Hastigerina murrayi* Thomson figured by Thomson (1876) as the lower specimen on his plate 22 and subsequently refigured by Brady (1884) on plate 83, figure 4, as *Hastigerina pelagica* (d'Orbigny), the specimen now registered in the British Museum (Natural History), London, as slide number ZF 1562 and encircled on that slide in black ink (Canada balsam mount) as the *lectotype* of *Hastigerina murrayi* 1876 and also as the *neotype* of *Nonionina pelagica* d'Orbigny 1839. The Secretary to the International Commission on Zoological Nomenclature is being informed of this in accordance with the Copenhagen Decisions.

Consequent upon this, *Hastigerina murrayi* Thomson 1876 becomes an objective junior synonym of *Nonionina pelagica* d'Orbigny 1839.

Morphology: This species, including the neotype, has been adequately described by Brady (1884). Bolli, Loeblich and Tappan (1957, p. 29) doubted that *Nonionina pelagica* d'Orbigny and *Hastigerina murrayi* Thomson were synonymous because ... "the aperture is so large and characteristic in *H. murrayi*" ... but in d'Orbigny's illustration and description of *N. pelagica* ... "no mention is made of an aperture nor is one shown on the drawing." The lectotype of *H. murrayi* actually possesses a very narrow slit-like aperture, a feature which was clearly shown in the drawings of this specimen published both by Thomson and Brady. We believe that in life the terminal aperture of this species is typically narrow, those specimens which have a highly arched terminal aperture owing that character to resorption (probably a septal aperture with the last chamber destroyed). Brady noted that the forms with the highly arched aperture were specimens from bottom dredgings and were "dead empty shells." The forms now mounted in Canada balsam with the narrow aperture are surface specimens taken in life and with the protoplasm still present.

Hastigerina pelagica appears to have an exceedingly short true trochospiral stage, and consequently, it appears to be more advanced morphologically than *H. (H.) siphonifera* (d'Orbigny), which is borne out by its almost unique possession of trigonal-prismatic spines, and by its shorter stratigraphic range. *H. (H.) siphonifera* is known from uppermost Burdigalian to Recent, while *H. (H.) pelagica* is definitely known only from Pliocene to Recent (although there are unconfirmed Tortonian records by



TEXT-FIGURE 2

Hastigerina siphonifera (d'Orbigny), $\times 100$ approximately. This specimen is the lectotype, here designated, of *Globigerina siphonifera* d'Orbigny 1839, from Cuba, probably from Recent beach sands. Specimen deposited in the Alcide d'Orbigny collection of the Muséum Nationale de l'Histoire Naturelle, Paris. Maximum diameter of lectotype, 0.46 mm. Figures 2a, 2c, side views; figure 2b, apertural view; showing virtually planispiral coiling in the adult, the interiomarginal-equatorial symmetrical aperture and the hispidity of the surface.

A.G.I.P. Mineraria, 1957). It is highly probable that *H. (H.) siphonifera* is descended directly from *Globorotalia (Turborotalia) obesa* Bolli (Blow 1959) and gives rise to the planispiral *Hastigerina (Bolliella) adamsi* in the Pleistocene or Recent; *H. (Hastigerina) pelagica* is of unknown ancestry, but gives rise to the streptospiral *Hastigerinella digitata* in the Recent.

Figured hypotype from Beebe Station No. 996, depth 0-400 fathoms, Atlantic Ocean, is deposited in the British Museum (Natural History), Catalogue No. 1959. 5.11.743. Neotype (and lectotype of *H. murrayi*) is also deposited in the British Museum (Natural History) Catalogue Number ZF 1562 and this slide (Canada balsam mount) bears Wyville Thomson's monogram and also Brady's plate and figure numbers in his own handwriting. The actual neotype is encircled in black ink.

Hastigerina (Hastigerina) siphonifera d'Orbigny

Text-figures 2a-c, 3a-b

Globigerina siphonifera d'ORBIGNY, 1839, in de la SAGRA, Hist. Phys. et. Nat. de l'Ile de Cuba, Bertrand, Paris, vol. 8, p. 83, pl. 4, figs. 15-18. (lectotype designated below).

Cassidulina globulosa EGGER, 1857, Neues Jahrb. Min. Geogn. Geol. Petref.-Kunde, Stuttgart, p. 296, pl. 11, fig. 4 only (not lectotype, not figs. 5-7).

Globigerina aequilateralis BRADY, 1879, Quart. Jour. Micr. Sci., London, n. s., vol. 19, p. 285.

Globigerina aequilateralis BRADY, 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 605, pl. 80, figs. 18-21 (lectotype designated below).

Globigerinella aequilateralis (Brady). - CUSHMAN, 1927, Cushman Lab. Foram. Res., Contr., Sharon, Mass., vol. 3, pt. 1, no. 39, p. 87.

Globigerinella aequilateralis (Brady). - CUSHMAN, 1928, Cushman Lab. Foram. Res., Spec. Publ., no. 1, pp. 302, 304, pl. 47, figs. 4-5.

Hastigerina aequilateralis (Brady). - BOLLI, LOEBLICH and TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, pt. 1, p. 29, pl. 3, fig. 4.

Globigerinella aequilateralis (Brady). - BRADSHAW, 1959, Cushman Found. Foram. Res., Contr., vol. 10, pt. 2, p. 38, pl. 7, figs. 1-2.

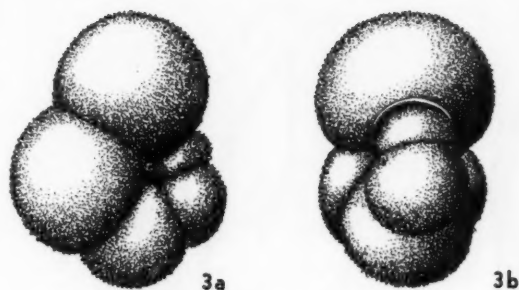
Taxonomy: During our visit to the Muséum National de l'Histoire Naturelle, Paris, the type specimen of *Globigerina siphonifera* d'Orbigny was found. Only a single specimen was present, mounted on a glass slip contained in a glass tube which, in turn, was stuck onto a thick cardboard base. On the reverse of the cardboard tube base d'Orbigny's original label was pasted on with the following inscription in d'Orbigny's own handwriting (*vide* M. P. Marie):

	IV
Cuba	15-18
	<i>Globigerina</i>
	<i>Siphonifera</i>

According to MM. P. Marie and M. Lys, d'Orbigny originally placed his specimens in very small glass bottles with a triangular-shaped brown paper label stuck between the cork and the neck of the bottle. Some of these small bottles with their labels are still extant in the Alcide d'Orbigny collection. However, much of d'Orbigny's collection was remounted by Terquem at an unknown date and the specimens remounted by Terquem form the only syntypic series for each species. Thus the specimen here described and designated as lectotype is considered to be syntypic and this is substantiated by the fact that Terquem pasted d'Orbigny's original label on the back of the tube base. The lectotype of *Globigerina siphonifera* d'Orbigny 1839 is hereby designated and has been isolated into a single-celled cardboard slide and remains in the collections of the Muséum National de l'Histoire Naturelle, Paris. Text figure 2a-c are camera lucida drawings of the lectotype. It is hoped to produce a microphotograph of the lectotype and this will be published in due course.

In 1857, J. G. Egger described *Cassidulina globulosa* from the Miocene of north Bavaria; his illustrated specimens appear to comprise two different genera (a), pl. 11, fig. 4, being planispiral and (b), pl. 11, figs. 5-7, having a cassiduline-like coiling mode. It is probable

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TEXT-FIGURE 3

Hastigerina siphonifera (d'Orbigny), $\times 100$. This specimen is the lectotype of *Globigerina aequilateralis* Brady 1879, from Challenger Station No. 224, depth 1850 fathoms, Recent, North Pacific; B.M.(N.H.) Catalogue No. 1959.6.11.1. Maximum diameter of lectotype, 0.44 mm. Figure 3a, side view; figure 3b, apertural view; showing virtually planispiral coiling in the adult, the interior-marginal-equatorial symmetrical aperture, and the hispidity of the surface.

that the planispiral specimen belongs to the species *Globigerina siphonifera* d'Orbigny. In his description Egger explicitly stated that the chamber coiling was alternating; therefore, to avoid confusion, we hereby designate the specimen represented by pl. 11, fig. 6, (Egger, 1857), as the lectotype of *Cassidulina globulosa* Egger 1857.

In 1879, H. B. Brady described, but did not figure, *Globigerina aequilateralis* from the recent material collected by the Challenger Expedition. In 1884, Brady figured specimens of this species also from the Challenger material and at the same time amplified his original description.

Since it is not possible to determine which specimens in the Challenger Collection deposited in the British Museum (Natural History), London, were used by Brady in 1879 to form his original concept of the species we have selected a lectotype from material mounted by him not later than 1884. We agree with Dr. C. G. Adams of the British Museum (Natural History) that it is not possible to relate with complete certainty either of the two dry mounted specimens figured (Brady 1884, pl. 80, figs. 18, 19) to the actual specimens present in his slides, notwithstanding that one slide was marked in Brady's own handwriting as "pl. 80 figure 18", and the other slide as "pl. 80 figure 19". It is emphasized that both slides contain many very similar specimens. In consequence we have selected another specimen from Brady's syntypic series (actually from the slide marked "pl. 80, fig. 19", British Museum (Natural History) Catalogue Number ZF 1464) as the lectotype of *Globigerina aequilateralis* Brady 1879. This specimen came from Challenger station 224, depth 1850 fathoms, North Pacific and is now registered in the British Museum (Natural History) Catalogue Number 1959.6.11.1 (see text-fig. 3a-b).

Morphology: D'Orbigny (1839) in his original description, significantly stated that the spire was planar, and the aperture elongate. The "pointes tubuleuse" seem to refer to the characteristic hispidity and numerous spine bases of the species. In the specimen we designate as lectotype (see text-fig. 2a-c) the coiling is virtually planispiral but one side is slightly more involute than the other and there is also an indication that there is a definite earlier trochospiral stage. D'Orbigny's original specimen (according to his writing) was $\frac{1}{3}$ of a mm. in diameter; the lectotype is 0.46 mm. maximum diameter and probably represents a more perfectly planispiral and later growth stage than that of d'Orbigny's original illustrated specimen. The primary aperture of the lectotype is a low equatorial, interior-marginal arch and extends into the ventral and dorsal umbilici. The aperture is bordered by a thin symmetrical, perforate lip of constant breadth. Relict apertures are present in the umbilical margins of the penultimate chamber.

The specimen selected by us as the lectotype of *Globigerina aequilateralis* Brady is virtually identical in all respects to the lectotype of *G. siphonifera* d'Orbigny (see text-figs. 2 and 3). Brady also shows in his pl. 80, figure 20 (sectioned specimen) the early trochospiral stage of "*aequilateralis*." This feature is present in all Brady's sectioned material and can be also observed in all of Brady's whole specimens. Brady illustrates (1884, pl. 80, fig. 18a) a specimen which shows a degree of uncoiling and many such specimens are present in the Brady Collection. From our examination of Brady's material we are convinced that the type represented by fig. 18a, pl. 80 has accidentally lost its very early stage; also in the Brady Collection specimens showing every complete gradation between the extremes of uncoiling and tightly coiled specimens is present. Some relationship to sexual dimorphism may be present in this feature but it seems highly unlikely that this character of uncoiling is of any taxonomic importance. Small abortive last chambers are common in this species and these are often detached from the penultimate whorl giving an uncoiling appearance to the test.

Cushman in 1927, erected the genus *Globigerinella* with *Globigerina aequilateralis* Brady as the type species distinguishing it from *Hastigerina* purely on the nature and distribution of the spines. Whilst we agree that there is a difference in the nature of the spines, it is considered, at this stage, not to be of supraspecific value.

In both cases *H. pelagica* and *H. siphonifera* (= *H. aequilateralis*) have a short initial trochospire becoming virtually planispiral, often increasingly evolute in ontogeny, and normally possessing a low slit-like, interior-marginal-equatorial primary aperture. Accordingly we agree with Bolli, Loeblich and Tappan (1957) in regarding *Globigerinella* Cushman 1927 as a junior synonym of *Hastigerina* Thomson, 1876 (see also Blow 1959).



TEXT-FIGURE 4

Hastigerina (Bolliella) adamsi Banner and Blow, $\times 50$; reproduction of original drawing (after Banner and Blow 1959) of holotype, B.M. (N.H.) Catalogue No. 1958.8.18.1; from 580 fathoms, off the Kai Islands (Challenger Station 191A), Recent, Indo-Pacific. Figure 4a and 4c, side views; figure 4b, apertural view; showing virtually planispiral coiling, symmetrical, interiomarginal equatorial aperture, and single radial elongations of the later chambers.

Subgenus **BOLLIELLA** Banner and Blow, 1959

Type species: *Hastigerina (Bolliella) adamsi*
Banner and Blow, 1959

Hastigerina (Bolliella) adamsi Banner and Blow, 1959
Text-figures 4a, b, c

Globigerina digitata BRADY, 1884 (part), Challenger Exped. 1873-76, Rept., London, Zool. vol. 9, pt. 22, pl. 82, fig. 6 (holotype), fig. 7 (paratype).

Hastigerinella digitata (Brady). — CUSHMAN, TODD and POST, 1954, U. S. Geol. Surv., Prof. Pap. no. 260-H, p. 369, pl. 91, figs. 9, 10.

Globigerinella sp. — BRADSHAW, 1959, Cushman Found. Foram. Res., Contr., vol. 10, pt. 2, p. 38, pl. 7, figs. 3, 4.

Hastigerina (Bolliella) adamsi BANNER and BLOW, 1959, Palaeontology, vol. 2, pt. 1, p. 13, text fig. 4, a-d.

Remarks: This form appears to have descended directly from *Hastigerina (Hastigerina siphonifera* d'Orbigny), and retains the wall-structure and fine hispidity of that species together with the typically *Hastigerina*-type of coiling (which is, initially, a flattened trochospire becoming virtually planispiral in ontogeny) and a typical *Hastigerina* aperture. There is no semblance of streptospiral coiling in this form. The chambers form single digitate elongations, without any bifurcation or multiplication as seen in *Hastigerinella*. It is probable that *Hastigerina (Bolliella)* is, like *Hastigerinella* and many other radially elongate forms of the Globigerinaceae, a phylogenetic end-form.

The holotype of *Hastigerina (Bolliella) adamsi* Banner and Blow is deposited in the British Museum (Natural History), Catalogue No. 1958.8.18.1.

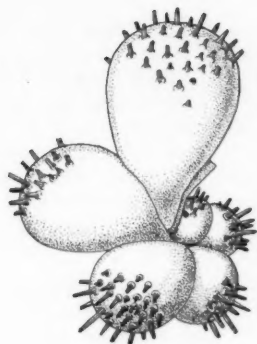
Genus ***Hastigerinella*** Cushman 1927, emended.

Type species: *Hastigerina digitata* Rhumbler 1911
(new binomen) (= *Hastigerinella rhumbleri* Galloway 1933).

Emended diagnosis: *Hastigerininae* (as emended, Banner and Blow, 1959) in which the coiling becomes streptospiral, and in which the chambers become radially elongate, and, in the later growth stages, bifurcate or trifurcate to give horn-like extensions of the chambers, or at least show potential bifurcation by bifocal concentration of spines distally.

Remarks: This genus is distinguished from *Hastigerina (Bolliella)* Banner and Blow 1959 by its streptospiral coiling and its multiple horn-like chamber extensions. It must be noted that *H. (Bolliella) adamsi* Banner and Blow 1959, the type species of *Bolliella*, never shows either streptospirality of multiple extensions from a single chamber, and that the resemblances between this and *Hastigerinella* are merely that resulting from their radial chamber elongations, a repetitive character which occurs frequently in the Globigerinaceae as a whole (e.g., as in the Hantkeninidae, *Clavigerinella*, *Praeglobotruncana (Clavibedbergella)*, *Schackoina (Leupoldina)* *Planomalina (Hastigerinoides)*; the Globotruncanidae, *Rugoglobigerina (Plummerita)*; and Globigerinidae, *Globorotalia (Beella)* subgen. nov.).

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TEXT-FIGURE 5

Hastigerinella digitata (Rhumbler), $\times 40$, from Beebe Station 1200, depth 600 fathoms; Recent, Atlantic. Hypotype, B.M.(N.H.) Catalogue No. 1959.5.11.742. Side view of immature form, showing how radial elongation of the chambers occurs early in ontogeny, and the asymmetrically and relatively densely distributed trigonally prismatic spines.

***Hastigerinella digitata* (Rhumbler), 1911, emended
Banner and Blow
Text-figures 5–8**

Hastigerina digitata RHUMBLER, 1911, Foram. Plankton-Exped. pt. 1, p. 202, pl. 37, figs. 9a, 9b, (?10).

Hastigerinella digitata (Rhumbler). – CUSHMAN, 1927, Cushman Lab. Foram. Res., Contr. vol. 3, pt. 1, p. 87, pl. 10, fig. 9 (after Rhumbler 1911).

Hastigerinella rhumbleri GALLOWAY, 1933, "A Manual of Foraminifera," Bloomington, Indiana, p. 333, pl. 30, fig. 9 (after Rhumbler, 1911) (*nomen nudum*, *nomen non necessarium*).

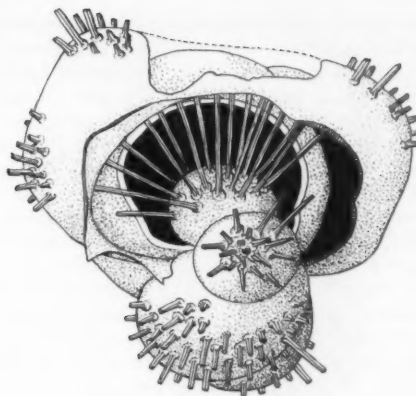
Hastigerina digitata var. *digitifera* Rhumbler. – WETZEL, 1949, (*nom. nud.*), The Micropaleontologist, vol. 3, no. 2, p. 40. (expl. pl. 37).

Hastigerinella rhumbleri (Galloway). – BOLLI, LOEBLICH and TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, p. 32, pl. 5, figs. 1, 2, (after Rhumbler 1911).

Hastigerinella rhumbleri Galloway. – BÉ, 1959, Micropaleontology, vol. 5, p. 83, pl. 2, fig. 23.

Hastigerinella rhumbleri Galloway. – BRADSHAW, 1959, Cushman Found. Foram. Res., Contr., vol. 10, pt. 2, p. 47, pl. 8, fig. 16.

Emended diagnosis: The very large streptospirally coiled test consists of about three whorls of inflated, well separated chambers, which become increasingly elongate during ontogeny, and are normal to the shifting axis of coiling. The streptospirality is accentuated during ontogeny. The earliest chambers are approximately ovoid in shape, with stout, elongate, solid, trigonally-prismatic spines concentrated on or restricted to the distal ends of the chambers. The chambers become increasingly elongate and pupoid during the second whorl (see text-figures 5, 7a, 8), and by the third whorl, the chambers broaden in apertural view; the distal spines then become concentrated laterally (see text-figure 7b).



TEXT-FIGURE 6

Hastigerinella digitata (Rhumbler), $\times 80$, from Beebe Station 1200, depth 600 fathoms; Recent, North Atlantic. Hypotype, B.M.(N.H.) Catalogue No. 1959.5.11.746. Apertural view of a young adult specimen, showing elongation of the last chamber parallel to the axis of coiling and bifocal concentration of spines, prior to the development of radial elongation and horn-like extension of the chambers. The fragile last chamber was broken during examination. The streptospiral coiling is apparent in this view.

This is followed by chambers which branch, forming at least two elongate, club-shaped (horn-like) extensions. The larger of the two extensions is often in that part of the plane of streptospiral coiling reached by the chamber; the shorter of the two extensions is correspondingly placed at a broad angle to the larger, almost normal to the plane of coiling.

The aperture is a very wide arch, interiomarginal, equatorial, elongate parallel to the axis of coiling, and it is symmetrically disposed about the plane of coiling of its chamber. Because the plane of coiling is constantly changing, and is different for each of the later chambers, the aperture of a succeeding chamber is not in line with that of the preceding chamber. The aperture possesses a thin, very finely perforate lip throughout its length. The wall is very thin and very finely perforate, proximally smooth, but distally spinose.

The hypotypes are deposited in the British Museum (Natural History), Catalogue Nos. 1959.5.11.742; 1959.5.11.744–746.

Remarks: This species, the only known species of *Hastigerinella*, shows a close relationship to *Hastigerina* (*Hastigerina*) *pelagica* d'Orbigny. As pointed out by Bé (in personal communication), these are the only two species of the Globigerinidae known to possess trigonally-prismatic spines. The distribution of these spines upon the chamber surface is superficially similar in each species, but even young pseudo-planispiral

specimens of *Hastigerinella digitata* possess a higher concentration of finer spines upon the distal chamber surfaces than is seen in specimens of *H. (Hastigerina) pelagica* of comparable size (see text-figures 1 and 5); also, the distribution of the spines in *H. (Hastigerina) pelagica* is symmetrical about the chamber, whereas the spinose area on an un-modified chamber of *Hastigerinella digitata* is asymmetrical, extending more on one side of the chamber than on the other. From specimens sent to us by Dr. Bé, and that illustrated by Bradshaw (1959), we have been able to interpret Rhumbler's original figures; text-figure 9c, which is an enlarged copy of Rhumbler's drawing, shows the shift of plane of coiling and the chamber bifurcation (see also Bradshaw, 1959, pl. 8, fig. 16), and confirms the high quality of Rhumbler's work. We feel that some previous workers have underestimated Rhumbler's standard of illustration, and have become confused in their interpretations by the multiple horn-like extensions of the later chambers. It may be suggested that *Hastigerina pelagica* is no more than a growth stage of *Hastigerinella digitata*; this is refuted both by our own specimens and by those illustrated by Bradshaw (1959, pl. 8, figs. 14-16).

Subfamily GLOBOROTALIINAE Cushman, 1927,
emended Banner and Blow, 1959
Genus *Globorotalia* Cushman, 1927,
emended Banner and Blow, 1959

Type species: *Pulvinulina menardii* (d'Orbigny) var.
tumida Brady, 1877

Subgenus **Beella** Banner and Blow, new subgenus

Type species: *Globigerina digitata* Brady, 1879 (partim),
emended. Banner and Blow 1959 =
Globorotalia (Beella) digitata (Brady)

Diagnosis: *Globorotalia* (as emended by Banner and Blow, 1959) in which the adult chambers become radially elongate. The aperture remains interiomarginal, umbilical-extraumbilical, ventral throughout ontogeny, not extending beyond the periphery onto the dorsal side. No carinae present.

Remarks: This subgenus differs from all superficially similar hantkeninid genera in lacking portici (Banner and Blow, 1959). It differs from all *Hastigerininae* by its typical lipped globorotalid aperture which never becomes interiomarginal-equatorial in position. *Hastigerinella bermudezi* Bolli 1957, and possibly *Globigerina radians* Egger 1893, are believed to belong to *Globorotalia (Beella)*. We have observed other forms, especially in recent material (as yet undescribed), which are also referable to this subgenus.

This subgenus is named for Dr. Allan Bé in recognition of his work on the ecology of recent *Globigerinaceae*, of his advice in discussion and of his help in supplying valuable and rare material.

Globorotalia (Beella) digitata (Brady)

Text-figures 11 a-c

Globigerina digitata BRADY (part), 1879, Quar. Jour. Micr. Soc. London, n. s., vol. 19, p. 286, (no figures).

Globigerina digitata BRADY (part), 1884, Challenger Exped. 1873-76 Rept., London, Zool., vol. 9 (pt. 22), pl. 80, figs. 6-10 (only).

Hastigerinella digitata (Brady). - BOLLI, LOEBLICH and TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, p. 32, pl. 5, figs. 3a, 3b.

Globigerina digitata (Brady). - PARKER, 1958, Repts. Swedish Deep-Sea Exped., 1947-48, vol. 8, fasc. 2, no. 4, pp. 276-7, pl. 5, fig. 8.

Globorotalia (Hastigerinella) digitata (Brady). - BANNER and BLOW, 1959, Palaeontology, vol. 2, pt. 1 (with synonymy), p. 16, Text. fig. 4c.

Parker (1958, pp. 276-7) restricted the name *Globigerina digitata* Brady to the syntypic series of forms illustrated by Brady (1884) on his plate 80, figs. 6-10. The name *digitata* was similarly restricted by us (1959), when a lectotype, here figured, was designated. Parker's illustrations (op. cit., pl. 5, fig. 8) show considerable variation in her specimens assigned to this species, but a similar range of variation is present in the "Challenger" Expedition specimens included in *Globigerina digitata*.

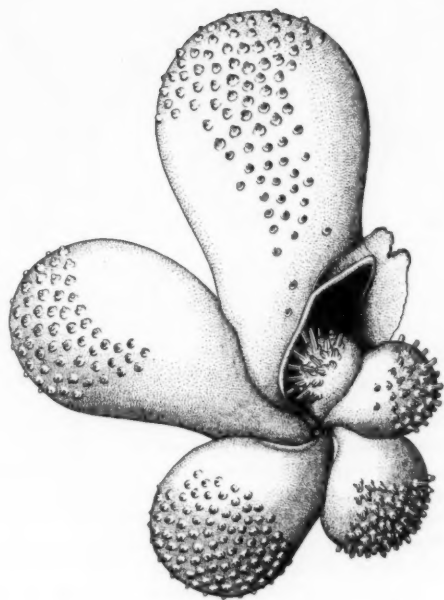
TEXT-FIGURE 7

Hastigerinella digitata (Rhumbler), $\times 40$, from Beebe Station 1200, depth 600 fathoms; Recent, North Atlantic. B.M. (N.H.) Catalogue No. 1959.5.11.745; hypotype. Figure 7a, side view; showing elongation of the later chambers, asymmetrical distribution of the spines and the small relict apertures present on two of the chambers, within the umbilicus. Figure 7b, apertural view; showing the streptospiral coiling of the test, and the broadening of the last chamber with concurrent bifocal concentration of the spines, prior to bifurcation of the chambers. The extremely fragile, two-horned last-formed chamber was broken off during examination.

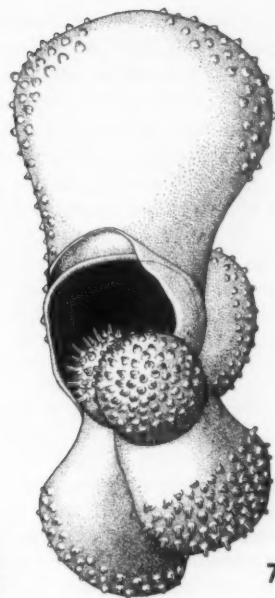
TEXT-FIGURE 8

Hastigerinella digitata (Rhumbler), $\times 40$, from Beebe Station 1200, depth 600 fathoms; Recent, North Atlantic. Hypotype, B.M. (N.H.) Catalogue No. 1959.5.11.744. Figure 8a, side view; showing bifurcation of the last two chambers; figure 8b, apertural view; showing streptospiral coiling, bifurcation of the last two chambers, distribution of the spines, and the broad high aperture; figure 8c, side view, opposite to fig. 8a; showing broader umbilicus consequent upon the streptospiral coiling, and the asymmetrical distribution of the spines. One horn of the last chamber has been lost, but is here reconstructed from earlier observations.

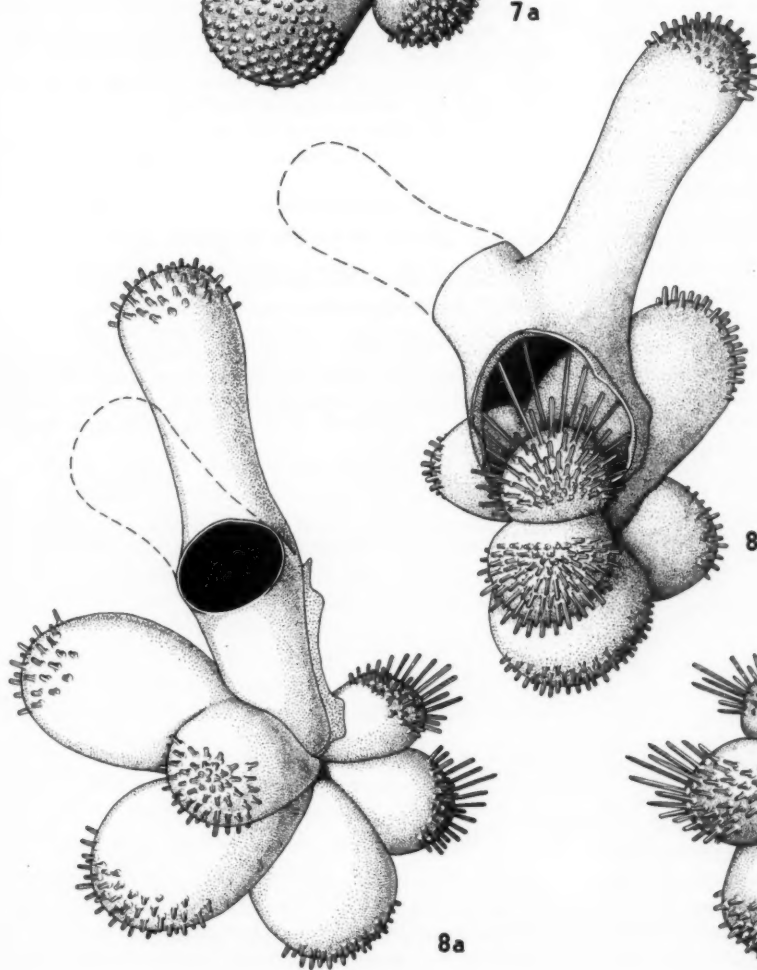
HASTIGERININAE



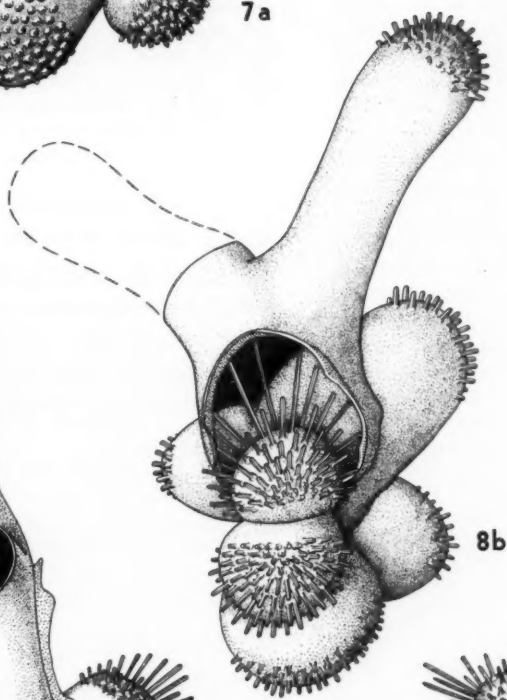
7a



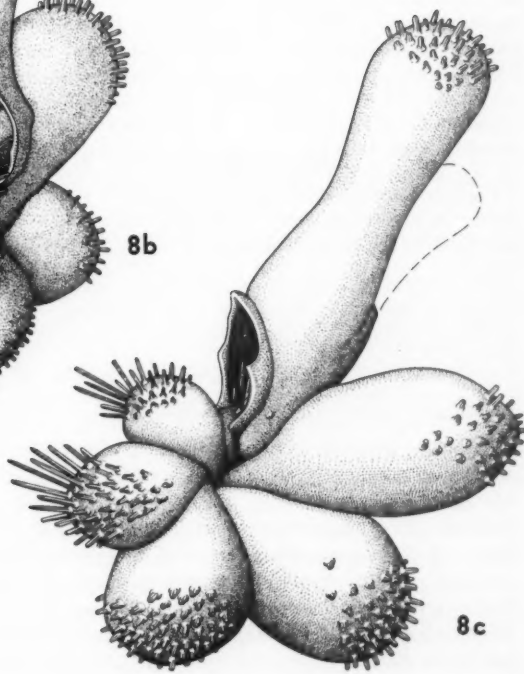
7b



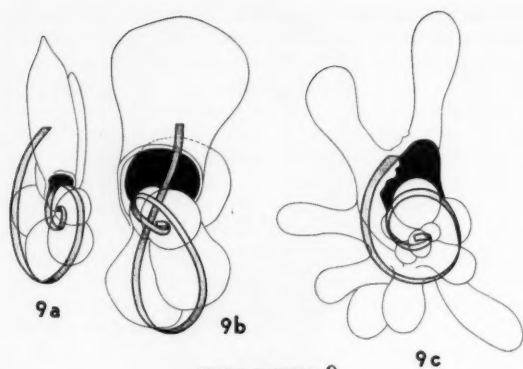
8a



8b



8c



TEXT-FIGURE 9

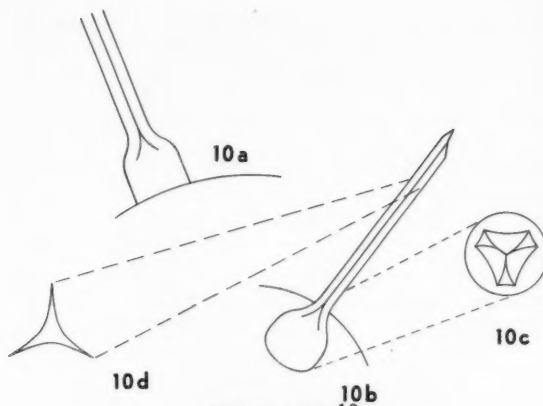
Diagrams to show coiling modes in *Hastigerina* (*Bolliella*) and in *Hastigerinella*. The shaded "ribbon" illustrates how the axis of coiling shifts in the streptospiral *Hastigerinella*, but remains constant in the virtually planispiral *Hastigerina* (*Bolliella*). The length of the "ribbon" shows the curve of test growth, following the progressive addition of the chambers; the breadth of the "ribbon" is parallel to the axis of coiling at any stage during growth. Figure 9a, apertural view of *Hastigerina* (*Bolliella*) *adamsi*, after Banner and Blow, 1959, \times ca. 33; figure 9b, apertural view of *Hastigerinella digitata* (Rhumbler), after text-figure 7b, this paper, \times 20; figure 9c, oblique view of *Hastigerinella digitata* (Rhumbler), after Rhumbler, 1911, \times ca. 11. If figure 9c is rotated through an angle of about 45° into the true apertural view, it will be seen that it has the same coiling mode as that shown in figure 9b. The bifurcation of the later chambers can be seen clearly on Rhumbler's figure.

by Brady and as now restricted. In some specimens the aperture is high and broad, but in others, where the last chamber is more ventral in position than usual (i. e., when the trochospiral coiling is intensified in ontogeny) the aperture may be relatively narrow. In either case, the aperture extends from the umbilicus to the broadly rounded periphery.

The lectotype of *Globigerina digitata* Brady 1879 = *Globorotalia* (*Beella*) *digitata* (Brady) is deposited in the British Museum (Natural History), Catalogue No. 1958.8.18.3.

CLASSIFICATION OF THE GLOBIGERINACEAE

Following from the redescrptions given above, it has become necessary to emend certain parts of the key to the genera and subgenera of the Globigerinaceae given in our previous paper (Banner and Blow, 1959): these emendations affect the classification of part of the Globorotaliinae (op. cit., pp. 6, 16.) and the Hastigerininae (op. cit., pp. 7, 12). The revised parts of the key, in an abbreviated form, are given below:



TEXT-FIGURE 10

Diagrams illustrating the form of the trigonally prismatic spines of *Hastigerina pelagica* and *Hastigerinella digitata*. Figure 10a and 10b showing a spine in profile and oblique views, \times ca. 315; the proximal sub-cylindrical to sub-conical boss is surmounted by the more slender trigonal spine. Figure 10c shows the idealised spine in plan view, and figure 10d shows a crosssection across the distal part of the spine, \times ca. 2160.

Family **Globigerinidae** Carpenter, 1862,
emended Banner and Blow, 1959

Subfamily **Globorotaliinae** Cushman, 1927,
emended Banner and Blow, 1959

Diagnosis: Globigerinidae (as emended) in which the test is clearly trochoid, possessing a primary aperture which is umbilical-extraumbilical and ventral in ontogeny and in the adult, not extending onto the dorsal surface of the test.

I. Test uniformly trochospiral throughout life:

1. No dorsal supplementary apertures:

genus: *Globorotalia* Cushman, 1927

(a) Test with an imperforate peripheral carina, at least in part:

subgenus: *Globorotalia*

(b) Test without an imperforate peripheral carina:

(i) Chambers not radially elongate:

subgenus: *Turborotalia* Cushman and Bermudez, 1949

(ii) Chambers radially elongate:

subgenus: *Beella* Banner and Blow, new subgenus (lower Miocene — Recent)

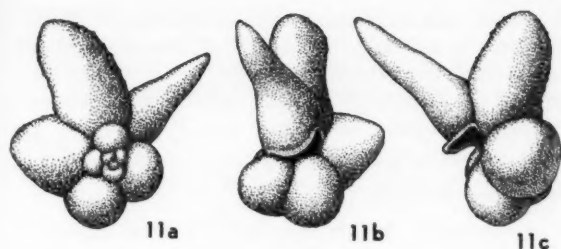
2. With dorsal supplementary apertures:

genus: *Truncorotaloides* Bronnimann and Bermudez, 1953.

II. Test becoming streptospiral in adult:

genus: *Pulleniatina* Cushman, 1927.

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TEXT-FIGURE 11

Globorotalia (Beella) digitata (Brady), $\times 60$, from "Challenger" Station 338, depth 1990 fathoms, Recent, North Atlantic. Lectotype of *Globigerina digitata* Brady 1879; B.M. (N.H.) Catalogue No.1958.8.18.3. This is a refiguring of the specimen illustrated by Brady, 1884, on pl. 80, fig. 10; it was amongst those designated as the restricted syntypic series of *G. digitata* by Parker, 1958, and was designated lectotype of the species by us in 1959. Figure 11a, dorsal view; showing elongation of the chambers in a radial direction in the second whorl; figure 11b, ventral view, showing slightly misplaced last chamber, which still possesses a distinctly umbilical-extraumbilical aperture; figure 11c, peripheral view, showing the trochospiral coiling, and the high aperture. These figures show the close relationship between this form and *Globorotalia (Turborotalia)*.

Subfamily **Hastigerininae** Bolli, Loeblich and Tappan, 1957, emended Banner and Blow, 1959

Diagnosis: Globigerinidae (as emended) in which the test is initially trochospiral, but becoming nearly, although imperfectly, planispiral in the adult and/or during ontogeny, advanced forms becoming streptospiral; the aperture is umbilical-extraumbilical-equatorial in the adult bi-umbilicate test.

- I. Adult coiling regular, planispiral or virtually planispiral:
 - genus: *Hastigerina* Thomson, 1876
 - 1. Chambers not radially elongate in the adult:
 - subgenus: *Hastigerina*
 - 2. Chambers with simple single radial elongations in the adult:
 - subgenus: *Bolliella* Banner and Blow, 1959
- II. Adult coiling streptospiral:
 1. Chambers elongate in the adult; often with multiple horn-like extensions:
 - genus: *Hastigerinella* Cushman, 1927 (Recent).

DISCUSSION

In our previous paper (Banner and Blow, 1959) we discussed in considerable detail the evidence given by the stratigraphic record for the value of the biocharacters which can be recognised in both fossil

and recent members of the Globigerinaceae. We concluded that many of the gross modifications, often used by earlier workers to define higher taxonomic units, were iterative. This present paper serves to emphasize still further the iterative nature of the streptospiral coiling mode and the elongate chamber shape, which are only two of the many biocharacters which have been repeated in time in many distantly related stocks. The basis for distinguishing between iterative and non-iterative characters, the latter forming the fundamental basis of our classification, is fully discussed in our earlier work (op. cit.).

The genus *Hastigerinella* is the streptospiral member of the Hastigerininae, morphologically paralleling the streptospiral *Pulleniatina*, which belongs to the Globorotaliinae. The gross pseudomorphy formed by chamber elongation independently in *Hastigerinella* and in *Hastigerina (Bolliella)*, when examined in detail, shows that the chamber elongations are fundamentally of a different nature: the elongate chambers of *H. (Bolliella) adamsi* show, by their simplicity and uniform hispidity, close affinity to its ancestral *Hastigerina (Hastigerina) siphonifera*, whereas the multiple extensions of the chambers of *Hastigerinella digitata*, with their restricted and characteristic spinosity, show not only close affinity to the ancestral *Hastigerina (H.) pelagica*, but the probable effect on chamber shape permitted or induced by a changed coiling mode. The elongate chambers present in various species referable to *Globorotalia (Beella)* show the simplicity of form which would be expected in a test which is regularly coiled.

The bifurcation of the elongate chambers in *Hastigerinella* recalls the bipartite, elongate chambers of *Schackoina (Leupoldina)*. These are, however, only superficially similar. In fully developed specimens of *S. (Leupoldina)* (Bolli, 1957, pl. 2, figs. 5-9), the primary equatorial aperture becomes subdivided and bipartite in a manner typical of many species in its subfamily, the Planomaliniinae (Banner and Blow, 1959). This bipartition is, in fact, incipient biseriality in an otherwise planispiral test, and is fundamentally different from the bifurcation (as distinct from bipartition) of the elongate chambers in *Hastigerinella*, where the primary equatorial aperture remains high and undivided, and the chamber asymmetry reflects the asymmetrical coiling mode. From this, it may be seen that whilst many of the individual biocharacters, such as over-all test and chamber shape, coiling modes and apertural positions, may be quite accurately repeated in time, they are often only repeated singly. There are only

a few examples where biocharacters of this sort are completely repeated in combination. Whilst this may help to distinguish between some stratigraphically isolated but superficially homeomorphic (pseudomorphic) genera, in other cases it is only the external accessory apertural structures which are the biocharacters of fundamental taxonomic importance. It is these accessory apertural structures which we have taken as the basis of our full classification (Banner and Blow 1959). Thus, the stocks of the Cretaceous *Planomalina* (*Hastigerinoides*) (Hantkeninidae) and the Recent *Hastigerina* (*Bolliella*) (Globigerinidae) are considered to be genetically quite distinct yet it is only the presence of portici in *P.* (*Hastigerinoides*) and lips in *H.* (*Bolliella*) that allows an unambiguous supraspecific distinction to be drawn. Similarly, *Globorotalia* (*Beella*) differs from *Globorotalia* (*Turborotalia*) in the same way as *Praeglobotruncana* (*Clavibergella*) differs from *P.* (*Hedbergella*), but differs from *Praeglobotruncana*, s.l., in its external apertural structures. There is no major morphological distinction, except that based on portici and lips, even though the genera occur at very different geological horizons (Banner and Blow 1959).

Hastigerina (*Bolliella*), *Hastigerinella* and *Globorotalia* (*Beella*) like their analogues in the Cretaceous and Eocene, are phylogenetic end forms; they, again like their Cretaceous and Eocene analogues, are of relatively short stratigraphic range, and species of each are clearly derived from different species of the parent genus. To illustrate this, Blow (1959) has pointed out that *Globorotalia* (*Beella*) *bermudezi* (Bolli) possesses early ontogenetic stages of a *Globorotalia* (*Turborotalia*) and is stratigraphically isolated, so that this species shows no direct relationship with any known Recent species of *Globorotalia* (*Beella*).

Hastigerina (*Bolliella*), *Hastigerinella* and *Globorotalia* (*Beella*) *digitata* (Brady) have all arisen suddenly in Recent times (not excluding the possibility of their appearance in the latest Pleistocene), even though the ancestors of the first two forms are known as Miocene. This, together with a consideration of much Recent material collected by the "Challenger", "Discovery", and "Terra Nova" expeditions, seen by us in the collections of the British Museum (Natural History), leads us to consider the possibility that at (or since) the close of Pleistocene times, there has been a considerable burst of evolution within the Globigerinidae probably comparable to that seen in the Aquitanian. The appearance of radially elongate, digitate forms seems highly significant when seen in the context of the history of the Globigerinaceae as

a whole, and their taxonomic relationships should be viewed, not only in the light of their zoological affinities at the present day, but also by taking due note of the phylogeny and stratigraphic distribution of their fossil pseudomorphs.

MOUNTING TECHNIQUE

The specimens of *Hastigerinella digitata* and *Hastigerina pelagica* supplied by Dr. Allan Bé were preserved in seawater with an added preservative, thus retaining the protoplasm. The extremely fragile nature of the tests precluded any form of dry mounting; as it was, the extremely long, fragile spines present in life were largely broken during transit. The specimens have now been mounted in glycerine jelly, within deep perspex cells fixed to glass microscope slides, and sealed with lacquer. Even though the tests were extremely delicate, a detailed examination of the morphology of these specimens was considered essential, whatever the risk of damage, and although great care was taken, some minor breakages could not be avoided. Their mounting is now permanent.

The specimens of *Hastigerina* (*Bolliella*) and *Globorotalia* (*Beella*) which are figured here, are mounted dry in single-celled cardboard slides.

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HASTIGERININAE

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ABSTRACT: *The Archaeomonadaceae of the Calvert formation (Miocene) of Maryland were studied morphologically and taxonomically. Two genera with fifteen species, four of which are new, are described and illustrated. A history of the study of the group with a review of the existing genera is given.*

The Archaeomonadaceae of the Calvert formation (Miocene) of Maryland

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INTRODUCTION

Archaeomonadaceae in the Calvert formation (Miocene) of Maryland were observed during an earlier investigation of the silicoflagellates (Tynan, 1957). A search of the literature has revealed no reference to the group in the English language. The object of this paper is to describe and illustrate the Archaeomonadaceae occurring in the Calvert formation at Randle Cliff Beach, Calvert County, Maryland.

Sincere appreciation is expressed to Dr. L. R. Wilson for his interest and encouragement during the course of the investigation.

STRATIGRAPHY

The Miocene deposits of the Middle Atlantic slope have been described under the name of the Chesapeake group (Darton, 1891). In Maryland, the Chesapeake group is composed in ascending order of the Calvert, Choptank, and the St. Marys formations. The Calvert formation (Shattuck, 1902) lies at the base of the Chesapeake group in Maryland and takes its name from Calvert County where it is typically developed and exposed for nearly thirty miles in the Calvert Cliffs along the eastern border of Calvert County from Chesapeake Beach to Drum Point. The general stratigraphy of the area has been reviewed by the writer in a previous paper (1957, p. 127). A detailed discussion may be found in Shattuck, 1904. Randle Cliff Beach, Calvert County, Maryland, was selected for sampling as a typical section of the Calvert is there exposed and easily accessible for study. The section sampled includes the upper three feet of Shattuck's zone three of the Fairhaven diatomaceous earth member to approximately zone ten of the Plum Point marls member of the Calvert formation.

PREPARATION

The samples were prepared for study in the following manner. Each sample was treated individually with concentrated hydrochloric, nitric and sulphuric acids. In each case, the reaction was allowed to run to completion in cold acid and then boiled for approximately ten minutes. After the last acid treatment, the sample was washed several times in distilled water until all traces of acidity were removed. Separation of the fossils from the detritus was accomplished by placing a sample in a 600 ml. glass beaker and adding water until the total volume was 300 mls. The sample was then agitated until all particles were in suspension. The sample was then allowed to settle for a controlled time period. The time period was established by experimentation for each sample and was found in this study to vary from one and a half to two minutes. After settling for the determined time period, 100 mls. were decanted into a second beaker and saved. Distilled water was again added to the first beaker to bring the total volume up to 300 mls. Agitation, decantation, and addition of distilled water was continued until microscopic examination of the decant showed an absence of fossil material in the decant. The decant collected in the second beaker was then filtered and the residue of fossil material was dried and stored. Strew slides were made using Hyrax as a mounting medium.

HISTORY

The history of archaeomonad studies is short. Deflandre (1932) introduced the group into paleontological literature with the description of *Lith-archaeocystis costata* as a new genus and species from the diatomite deposits of Kusnetz in Russia. At the time, this form could not be assigned to any known fossil group. Deflandre considered the genus

to be related to Chrysophyceae and in particular to the Chrysomonadina based on the morphology of the cyst. Until then, the only known fossil Chrysophyceae were the silicoflagellates and the coccolithophorids.

Deflandre (1932a) proposed the family Archaeomonadaceae to include a series of small, spherical, siliceous cysts which apparently formed a homogeneous group. In the new family Deflandre included the four new genera *Archaeomonas*, *Archaeosphaeridium*, *Litheusphaerella*, and *Amphilithopyxis*, as well as the previously described genus *Litharchaeocystis*. Deflandre stated that there is little doubt that the archaeomonads are related to the living chrysomonads and the family Archaeomonadaceae could be placed in the Class Chrysomonadineae, Subclass Chrysomonadeae, but would constitute an order other than the three included in the subclass. In subsequent papers, Deflandre (1932b, 1932c, 1933, and 1938) and Rampi (1940) described three additional genera and sixty-one species.

BIOLOGY AND CLASSIFICATION

The family Archaeomonadaceae (Deflandre, 1932a) includes a great number of forms widely distributed in fresh and marine waters. Little information is available concerning the biology of modern marine chrysomonads, and this is based on what is known about freshwater forms. In the modern freshwater chrysomonad, the classification is based on the soft body parts and the manner of reproduction, as well as the morphology of the cyst. In this group, a cyst may have two functions which cannot be determined from the cyst itself. It may be a true reproductive cyst of the organism or it may be the protective test of the organism in the flagellated state. The chrysomonads have the following life forms in the flagellated state, (1) no protective covering (*Chromulina*), (2) a protective envelope of siliceous scales (*Mallomonas*), (3) a cellulose envelope (*Dinobryon*), and (4) a siliceous test. In reproduction, the groups without a siliceous test in the flagellated state form a cyst. The reproductive cyst of one genus in many cases cannot be distinguished from that of other genera or from the siliceous test of genera in the flagellated state. As a result of this varied life habit, it is not possible to properly identify extant forms or classify fossil forms by an examination of the cyst alone.

Deflandre (1943) proposed a classification of the chrysomonads, emphasizing the fact that the taxonomy was artificial and erected only to facilitate study. According to Deflandre, the chrysomonads include fossil and modern, marine and freshwater

forms. He included forms identifiable as modern genera in the Chrysomonadina *sensu stricto*. Freshwater forms which could not be referred to modern genera were designated as Chrysostomataceae. Marine forms which could not be referred to modern genera were designated Archaeomonadaceae.

The family Archaeomonadaceae includes nine described genera. These are, (1) *Litharchaeocystis* Deflandre, 1932 with two species, (2) *Amphilithopyxis* Deflandre, 1932 with one species, (3) *Archaeosphaeridium* Deflandre, 1932 with seven species, (4) *Archaeomonas* Deflandre, 1932 with fifty-five species, (5) *Litheusphaerella* Deflandre, 1932 with two species, (6) *Pararchaeomonas* Deflandre, 1932 with two species, (7) *Lithuropyxis* Deflandre, 1933 with one species, (8) *Archaeomonadopsis* Deflandre, 1938 with four species, and (9) *Micrampulla* Hanna, 1927 with one species.

The genus *Micrampulla* Hanna (1927, p. 26, pl. 3, fig. 15; 1934, p. 355, pl. 48, fig. 6) is based on material from the Moreno shale, and was considered by the describer to be a diatom, possibly related to *Pterotheca* of *Kentrodiscus*. The general morphology suggests a closer relationship with the Archaeomonadaceae than with the diatoms. While the type specimen has not been examined, preparations of the Moreno shale were studied and found to contain not one but several different forms which could be assigned to this genus and which are undoubtedly archaeomonads.

DISCUSSION

The archaeomonads, with further investigation, may prove to have stratigraphic significance. Their pelagic habit and wide geographic distribution should make them useful in stratigraphic studies. The small size, averaging eight to ten microns, rarely twenty or more, permits recovery of great numbers from a relatively small sample. In the samples prepared for this study, a count of the diatoms and the archaeomonads revealed that the archaeomonads made up approximately four percent of the assemblage. Their small size has disadvantages since extremely high magnification is necessary for study. The organism is visible under 100 magnifications but not identifiable. Known forms are recognizable under 450 magnifications but close study of the ornamentation and pore structure must be made at higher magnification. The ornamentation is sometimes so small as to be close to the theoretical limits of resolution.

Archaeomonads have been recovered from diatomites, shales, marls, and silts. A comparison seen in

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this study indicates that while there are fewer numbers in the silts than in relatively pure diatomites, the preservation was equally good in both sediments.

The classification proposed by Deflandre has been followed in this study but the artificial nature of the taxonomy must be noted. The erection of taxonomic categories on environmental variations is not valid.

The archaeomonads have been reported from many parts of the world including the east and west coast of the United States, Hungary, Japan, Italy, Jutland, New Zealand, and Russia. Although many genera and species have been described, it is felt that the age relationships of many of the forms has not been validated. While it is not possible to give the stratigraphic ranges of the genera and species in detail, the maximum range of the group at the present time is from the Upper Cretaceous (Rampi, 1940) to the present (Deflandre, 1932c).

SYSTEMATIC DESCRIPTIONS

Family ARCHAEMONADACEAE Deflandre, 1932
Genus ARCHAEMONAS Deflandre, 1932

***Archaeomonas speciosa* Deflandre**
Plate 1, figure 1

Archaeomonas speciosa DEFLANDRE, 1932, Soc. Bot. France, Bull., vol. 79, p. 349, figs. 6-9.

Cyst spherical with a prominent neck, pierced by a cylindrical pore. Wall ornamented with a network of elevated ridges outlining fields of 3, 4, or 5 sides. The junction of the ridges is accentuated by small knobs or blunt spines which are raised slightly above the ridges. The neck joins the cyst in a gentle curve beginning at the midpoint of the neck. The cyst consists of a single layer of silica.

Diameter of cyst 5.7-7.2 microns. Height of neck .6-.9 microns. Diameter of neck 1.7-2.2 microns. Diameter of pore .9-1.1 microns.

Deflandre (1932) described this species from Maryland. Precise geographic and geologic information is not given. The species is the most abundant in the Calvert formation.

***Archaeomonas angulosa* Deflandre**
Plate 1, figure 2

Archaeomonas angulosa DEFLANDRE, 1933, Soc. Bot. France, Bull., vol. 80, p. 84, figs. 6, 7.

Cyst spherical with a prominent neck, pierced by a cylindrical pore. Wall ornamented with strong spines which are connected by an irregular network of prominent ridges. The ridges attain maximum elevation at

the juncture of the ridges and are at minimum elevation midway between the juncture. The neck joins the cyst in a gentle curve beginning at the midpoint of the neck. The cyst consists of a single layer of silica.

Diameter of cyst 6.6 microns. Height of neck .9 microns. Diameter of neck 1.7 microns. Diameter of pore 1.1 microns.

This species is easily distinguishable from *A. speciosa* by the much coarser reticular pattern of the ridges and the strong, sharply pointed spines. The species is abundant in the Calvert formation.

Deflandre (1933) described this species from deposits of Oamaru, Cormak's Top (Oligocene), New Zealand.

***Archaeomonas mangini* Deflandre**
Plate 1, figure 4

Archaeomonas mangini DEFLANDRE, 1932, Acad. Sci., C. R., vol. 194, p. 1861, fig. 2.

Cyst spherical with a prominent neck, pierced by a cylindrical pore. Wall ornamented with well developed conical spines. Spines are irregularly spaced and number 4-5 across the diameter of the cyst. The neck joins the cyst in a gentle curve beginning at the midpoint of the neck. The cyst consists of a single layer of silica.

Diameter of cyst 6.6 microns. Height of neck 1.1 microns. Diameter of neck 1.7 microns. Diameter of pore .9-1.1 microns.

Deflandre described this species from Maryland. Precise geographic and geologic information is not given. The species is numerous but not common in the Calvert formation.

***Archaeomonas vermiculosa* Deflandre**
Plate 1, figure 5

Archaeomonas vermiculosa DEFLANDRE, 1932, Soc. Bot. France, Bull., vol. 79, p. 348, fig. 4.

Cyst spherical with a low neck pierced by a cylindrical pore. Wall ornamented with raised ridges which are short, not connecting, and randomly oriented. In optical section, the ridges appear as rounded projections on the periphery of the cyst. The neck joins the cyst in a gentle curve beginning at the distal end of the neck. The cyst consists of a single layer of silica.

Diameter of cyst 6.1-7.8 microns. Height of neck .9 microns. Diameter of neck 2.2 microns. Diameter of pore 1.1 microns.

Deflandre described the species from Maryland and records it from deposits near Poplein (state not given) in the United States and from the Ile de Mors in Jutland. Precise geographic and geologic information is not given. The species is rare in the Calvert formation.

Archaeomonas cf. A. helminthophora Deflandre
Plate 1, figure 6

Archaeomonas helminthophora DEFLANDRE, 1933, Soc. Bot. France, Bull., vol. 80, p. 82, fig. 2.

Cyst spherical with a prominent neck, pierced by a cylindrical pore. The distal end of the neck is flared into a funnel projecting slightly from the body of the neck. Wall ornamented with raised ridges which are short and randomly oriented. Occasionally two or three of the ridges may join. In optical section, the ridges appear as rounded projections on the periphery of the cyst. The neck joins the cyst in a gentle curve beginning at the lowermost portion of the neck. The cyst consists of a single layer of silica.

Diameter of cyst 6.6 microns. Height of neck 1.1 microns. Diameter of the neck 1.7 microns, with funnel 2.2 microns. Diameter of pore .9–1.1 microns.

This species is similar in many respects to *Archaeomonas helminthophora* but varies in the structure of the neck and pore. The neck here is flared and the pore is funnel shaped at the distal end where in *A. helminthophora* the neck is a simple cylinder and the pore is parallel sided. The ornamentation is identical to *A. helminthophora*. The species is rare in the Calvert formation.

Archaeomonas cf. A. caulleryi Deflandre
Plate 1, figure 8

Archaeomonas caulleryi DEFLANDRE, 1933, Soc. Bot. France, Bull., vol. 80, p. 87, figs. 28–31.

Cyst spherical with a prominent neck pierced by a cylindrical pore. Wall devoid of ornamentation. The equator of the cysts is marked by an encircling flange projecting about two microns from the cyst and turned toward the apertural end of the cyst at an angle of approximately twenty degrees. The neck is broader at the proximal than the distal end so that the neck slopes outward to merge with the cyst in a gentle curve. A raised, rounded ridge originates at the equator and circles the cyst in an irregular manner up to but not quite joining the equatorial flange on the opposite side. The apertural half of the cyst is slightly flattened giving a slightly lenticular appearance to the cyst. The cyst consists of a single layer of silica.

Diameter of cyst 5.5 microns. Diameter of flange 8.3 microns. Height of neck 1.1 microns. Width of neck; distal 1.1 microns, proximal 1.7 microns. Diameter of pore .9 microns.

The species observed in the Calvert formation is assigned to *Archaeomonas caulleryi* although it differs in the placement of the equatorial flange and the number of ridges. The few specimens observed in the Calvert formation do not justify a positive identification. Deflandre described *Archaeomonas caulleryi* from the Ile de Mors, Jutland.

Archaeomonas areolata Deflandre
Plate 1, figure 10

Archaeomonas areolata DEFLANDRE, 1933, Soc. Bot. France, Bull., vol. 80, p. 83, fig. 4.

Cyst spherical, pierced by a simple pore. A very low neck or collar is present but is obscured by ornamentation. Wall ornamented by a reticular network of raised ridges outlining polygonal fields. Cyst consists of a single layer of silica.

Diameter of cyst 6.6 microns. Diameter of pore approximately 1.1 microns. Deflandre described the species from deposits of Karand, Hungary. This species is rare in the Calvert formation.

Archaeomonas inconspicua Deflandre
Plate 1, figure 12

Archaeomonas inconspicua DEFLANDRE, 1933, Soc. Bot. France, Bull., vol. 80, p. 82, fig. 1.

Cyst spherical, without neck, pierced by a simple pore. Cyst wall thin and devoid of ornamentation. Cyst consists of a single layer of silica.

Diameter of cyst 2.8–4.4 microns. Diameter of pore .6 microns.

Deflandre described this species from deposits of Karand, Hungary. Rampi (1940) reported the species from the Moreno shale (Upper Cretaceous) of California. This species is rare in the Calvert formation.

Archaeomonas reticulosa Deflandre
Plate 1, figure 13

Archaeomonas reticulosa DEFLANDRE, 1932, Soc. Bot. France, Bull., vol. 79, p. 351, figs. 20 and 21.

Cyst ovoid with a prominent neck pierced by a cylindrical pore. Wall ornamented by a reticular network of raised ridges outlining fields of 3, 4, and 5 sides. The ridges appear as spines in optical section. Cyst consists of a single layer of silica.

Dimensions: length of cyst 13.8 microns, width 12.0 microns. Height of neck 2.2 microns. Diameter of neck 3.9 microns. Diameter of pore 2.2 microns.

The specimens vary somewhat from the description of the species in that they do not have buttons or spines. In other respects they are identical with the description. Deflandre described the species from the Ile de Fuur, Jutland. The species is rare in the Calvert formation.

Archaeomonas multispinosa Tynan, new species
Plate 1, figure 3

Cyst spherical with a prominent neck, pierced by a round cylindrical pore. The distal end of the neck is flared into a funnel projecting slightly from the body of the neck. Wall ornamented with numerous sharply pointed spines,

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averaging 15 spines across the diameter of the cyst. The neck joins the cyst at a sharp angle. The cyst consists of a single layer of silica.

Diameter of cyst 5.5–7.2 microns. Height of neck 1.1 microns. Diameter of neck 1.7 microns, with funnel 2.2 microns. Diameter of pore .9–1.1 microns.

Holotype in the Oklahoma Palynological Repository, Oklahoma Geological Survey. Slide 12–1, coordinates 45.4, 114.0.

This species differs from *Archaeomonas dubia* Deflandre (1933, p. 84, fig. 10) in that the spines are more strongly developed, there is no indication of punctation, and the neck terminates distally in a funnel. The species is numerous but not common in the Calvert formation.

Archaeomonas wilsoni Tynan, new species

Plate 1, figure 7

Cyst spherical with a prominent neck pierced by a cylindrical pore. Wall devoid of ornamentation. The equator of the cyst is marked by an encircling flange projecting about two microns from the cyst and turned toward the apertural end of the cyst at an angle of approximately twenty degrees. The neck is broader at the proximal than the distal end so that the neck slopes outward to merge with the cyst in a gentle curve. The cyst consists of a single layer of silica.

Diameter of cyst 6.1–6.6 microns. Diameter of flange 7.8–8.3 microns. Height of neck 1.1 microns. Diameter of neck; distal 1.7 microns, proximal 2.2 microns. Diameter of pore 1.1 microns.

Holotype in the Oklahoma Palynological Repository, Oklahoma Geological Survey. Slide 14–1, coordinates 33.7, 110.7.

This species is similar to *Archaeomonas saturnus* in general appearance, but differs in that the cyst is spherical and not lenticular and the flange is narrow and projects outward at an angle of twenty degrees toward the apertural end rather than being broad and normal to the cyst. The pore is cylindrical and not a truncated cone as in *Archaeomonas saturnus*. This species is rare in the Calvert formation.

Archaeomonas mamillosa Tynan, new species

Plate 1, figure 9

Cyst spherical, very slightly flattened on the pore-bearing quarter, with a low, gently rounded neck pierced by a pore. The pore consists of two truncated cones of unequal size with the small ends opposed. The larger of the two truncated cones is distally located. Wall devoid of ornamentation. Cyst consists of a single layer of silica.

Diameter of cyst 8.8–11.0 microns. Height of neck 1.1 microns. Diameter of neck; proximal 2.8 microns, distal 2.2 microns. Diameter of outer pore opening 1.1 mi-

crons. Variations of the pore structure are plainly visible but not measureable.

Holotype in the Oklahoma Palynological Repository, Oklahoma Geological Survey. Slide 6–1, coordinates 36.3, 114.3.

Archaeomonas gracilis Tynan, new species

Plate 1, figure 11

Cyst spherical with a prominent neck pierced by a cylindrical pore. Wall ornamented by raised, rounded ridges running irregularly over the cyst. The ridges bifurcate and merge with no particular pattern. The neck is flared distally into a funnel projecting slightly from the body of the neck. Cyst consists of a single layer of silica.

Diameter of cyst 7.2–8.3 microns. Height of neck 1.1–1.7 microns. Diameter of neck 2.8 microns. Diameter of pore 1.1 microns.

Holotype in the Oklahoma Palynological Repository, Oklahoma Geological Survey. Slide 14–1, coordinates 30.8, 115.2.

This species differs from *Archaeomonas heteroptera* in that it has a well developed, flared neck and the ornamentation is not oriented but irregularly disposed over the cyst. This species is numerous in the Calvert formations.

Genus ARCHAESPHAERIDIUM Deflandre, 1932

Archaeosphaeridium cf. *A. ornatum* Deflandre

Plate 1, figure 15

Archaeosphaeridium ornatum DEFLANDRE, 1932, Soc. Bot. France, Bull., vol. 79, p. 352, fig. 31.

Cyst spherical with prominent low wide neck pierced by a pore. The pore is a truncated cone with the smaller end opening into the cyst. Wall ornamentation consists of numerous irregular raised ridges of no particular pattern. The length, width, and height, of the ridges is very variable. The ornamentation rises from a second layer of silica which overlies an inner smooth layer.

Diameter of cyst 22.6 microns, with ornamentation 25.9 microns. Height of neck 2.2 microns. Diameter of neck; distal 6.6 microns, proximal 9.9 microns. Diameter of pore; distal 3.3 microns, proximal 2.8 microns.

The Maryland specimens correspond to the description of *A. ornatum* except in the structure of the distal end of the neck. In *A. ornatum* the distal end of the neck has a saucer-shaped depression into which a cylindrical pore opens. In the Calvert specimens, the distal end of the neck is broad and flat and the pore is a truncated cone rather than a cylinder.

Deflandre described the species from deposits at Beach Haven, New Jersey. Precise geographic and geologic information is not given. The species is rare in the Calvert formation.

Archaeosphaeridium pachyceros Deflandre

Plate 1, figure 14

Archaeosphaeridium pachyceros DEFLANDRE, 1933, Soc. Bot. France, Bull., vol. 80, pp. 88-89, figs. 40 and 41.

Cyst spherical with a low wide neck pierced by a cylindrical pore. The pore opens into a saucer-shaped depression at the distal end of the neck. Wall smooth. Ornamentation consists of heavy, solid spines tapering to sharp point. Length and number variable.

Diameter of cyst 19.8-22.0 microns. Height of neck 1.1 microns. Diameter of neck; distal 7.2 microns, proximal 8.3 microns. Diameter of pore 2.8 microns. Length of spines 10-15 microns. Diameter of spines at base 2.8 microns.

Spines are broken in most of the Calvert specimens. The dimensions given are average dimensions taken from many different specimens.

Deflandre described this species from deposits at Beach Haven, New Jersey. Precise geographic and geologic information is not given. The species is very rare in the Calvert formation.

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PLATE 1

ALL MEASUREMENTS IN MICRONS

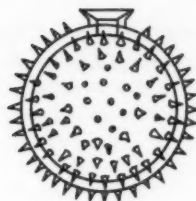
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2	<i>Archaeomonas angulosa</i> Deflandre	6.6μ	10	<i>Archaeomonas areolata</i> Deflandre	6.6μ
3	<i>Archaeomonas multispinosa</i> Tynan, n. sp.	6.6μ	11	<i>Archaeomonas gracilis</i> Tynan, n. sp.	7.2μ
4	<i>Archaeomonas mangini</i> Deflandre	6.6μ	12	<i>Archaeomonas inconspicua</i> Deflandre	2.8μ
5	<i>Archaeomonas vermiculosa</i> Deflandre	7.2μ	13	<i>Archaeomonas reticulosa</i> Deflandre	13.8μ
6	<i>Archaeomonas</i> cf. <i>A. helminthophora</i> Deflandre	6.6μ	14	<i>Archaeosphaeridium pachyceros</i> Deflandre	22.0μ
7	<i>Archaeomonas wilsoni</i> Tynan, n.sp.	6.1μ	15	<i>Archaeosphaeridium</i> cf. <i>A. ornatum</i> Deflandre	22.6μ
8	<i>Archaeomonas</i> cf. <i>A. caulleryi</i> Deflandre	5.5μ			



1



2



3



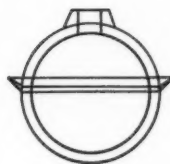
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6



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8



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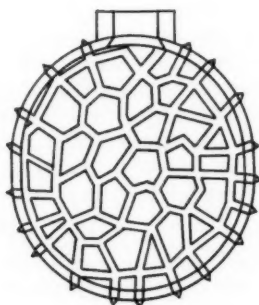
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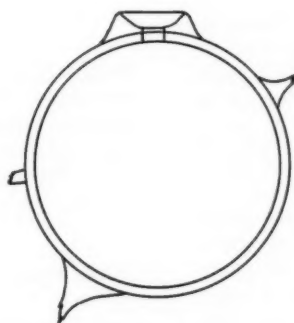
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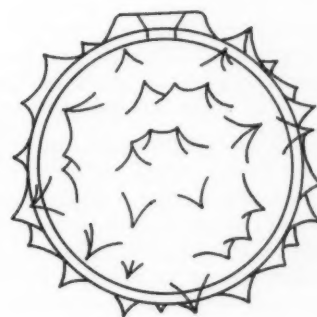
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15

ABSTRACT: The trends in variation of the different species groups of *Lenticulina* from the Lias are shown. The plexus of evolving forms is discussed and the stratigraphical significance of the various species groups is given. The gradation from the coiled lenticuline to an uncoiled at flabelline stage is demonstrated. The evolutionary, biological and stratigraphical aspects are stressed rather than the purely taxonomic approach. Some forms described by other authors are discussed, but a complete synonymy is not attempted.

Some species of *Lenticulina* and associated genera from the Lias of England

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INTRODUCTION

The author (1950a, p. 379) in a study of "Foraminifera from the Lower Lias of the Dorset Coast" dealt briefly with a *Lenticulina* plexus of smooth forms. It was found that the various morphological types could best be treated as part of a plexus of evolving forms. The record, however, was incomplete, but subsequent work has shown that the results obtained were substantially correct. In view of the fact that considerable confusion exists in the taxonomy of the species of *Lenticulina* from the Lias, and that a more complete record is now available, a further study of the group is desirable.

Several root-stocks, which may have been closely related in their early history, have been separated. These develop similar trends so that homeomorphy makes identification difficult. The dominant trends in variation are similar from both the Lias of the Dorset Coast and the more complete section shown by the Geological Survey boring at Stowell Park, Gloucestershire. That the trends are of stratigraphical value, is substantiated by the work of Bartenstein and Brand (1937) who described a similar sequence of forms from the Lias of north-west Germany. These authors, however, did not discuss the stratigraphical and evolutionary significance of the forms.

Growth stages of the forms show considerable differences and this has led to difficulty in determining species; young forms have often been given different names from their corresponding adults. Variants have been given specific names, although the forms are clearly linked by a series of gradations.

Lenticulina inaequistriata (Terquem) shows variation in the shape of the test and the ornament. Some of these trends have proved to be of stratigraphical use, in an important species having a limited stratigraphical range.

VARIATION AND SUCCESSION IN SMOOTH FORMS

Generally foraminifera are rare in the *planorbis* zone, but at some localities specimens belonging to a few species of *Lenticulina* are extremely abundant. In the lower zones of the lower Lias from Stowell Park all specimens of *Lenticulina* belong to one variable dominant group, namely Form A (plate 1).

The specimens belonging to Form A have an initial loosely coiled spire of three to five chambers, followed by curvilinear series of up to eight chambers. The cross-section is somewhat flattened except where the end chambers become swollen. In the uncoiled part of the test the chambers show little or no tendency to overlap onto the initial spire. The sutures are scarcely visible on the roughened surface of the test. A slight irregular keel may develop.

In the first group of variants, which grade from one to another as shown in plate 1, Form Aa is selected as the central morphological type. Form Aa has a small loosely coiled initial stage, common to all the variants, followed by two or three triangular shaped chambers in a short curvilinear series. Although there is no overlap onto the initial portion of the test, the uncoiled part is only just separate. The terminal, marginal aperture is not on a neck. A small keel usually occurs, irregular in its position on the periphery, and in its degree of development.

Form Af is rare, being developed from Form Aa by the addition of a curved parallel-sided chamber which overlaps onto the initial spire. A small irregular keel may occur, together with slightly indented sutures. Sometimes the aperture is on a slightly projecting neck. The normal Form Aa is usually followed by Forms Ab and Ac, in which a curvilinear series of chambers is developed. In Form Ab the series consists of low but broad chambers, so that there is a tendency for the test to broaden into a short broad spire. This tendency is, however, not developed far, as in some other forms of *Lenticulina*. Another abundant variant is Form Ac where the chambers increase in height, but only slightly in breadth so that the arcuate test is parallel-sided. In the rare Form Ad the end chambers are swollen and circular in cross-section. In Form Ae the end chamber is almost triangular in cross-section, and is smaller than the penultimate chamber. Form Ag is a further development of Form Ab; here a broad curvilinear series of chambers is developed, with the sides of the test diverging towards the apertural face.

Form B (plate 1) is small, compressed, consisting of a loose coil of one to three-quarters of a whorl, followed by a curvilinear series of small parallel-sided chambers. Variation is small except in the shape of the somewhat irregular end-chamber. A radiate, marginal aperture is either flush with the surface of the test or on a small neck. Usually Form B is rare and of sporadic occurrence, but occasionally the environment must have been suitable for larger specimens to develop.

Form C (plate 1) is a widespread and dominant form. The robust test often has a strongly developed keel on the earlier chambers. The form was mentioned by the author from similar beds (H. 57, 1950a, p. 381). Occurring near the top of the *angulatum* zone it remains dominant, if occasionally sporadic, until the *semicostatum* zone, but after, it rarely occurs till the *oxynotum* zone. The chambers are triangular and only overlap slightly the initial part of the test. At the apertural margin the chambers appear to be notched back. A broad keel occurs on a few specimens but is absent on the end-chambers. In both generations, a thick layer of calcite forms a pseudo-boss over the umbilicus, completely covering the initial chambers. The sutures are slightly depressed.

Somewhat similar variants to those of Form A occur. Although gradation exists between the variants, three are worthy of mention. In Form Ca, the most abundant variant, the pseudo-boss is eccentric in position, and apart from the apertural face a strong keel surrounds the whole periphery. As the test

grows this keel becomes stronger, but the edge may be slightly irregular, possibly due to the state of preservation. Early apertures protrude on necks, which become more pronounced as the test grows. Form Cb develops from Form Ca by the uncoiling of later chambers into either a rectilinear or curvilinear series; here the chambers become parallel-sided instead of triangular and the keel degenerates and finally disappears.

The initial stages of Form Cc are similar to Form Ca, but as the broad triangular chambers develop they become compressed and thin, as well as narrowing towards the umbilical boss. This early portion is followed by one to three (usually one), chevron-shaped chambers. Often the two "arms" of the chevron are almost equal in length. The aperture is radiate on a small apertural chamberlet.

Forms A and C predominate for most of the Lias from the *angulatum* to *turneri* zones. These forms together with Form B comprise the *Lenticulina* population which varies considerably in abundance from horizon to horizon. Although rare and sporadic, Form A occurs up to the *oxynotum* zone. In the *obtusum* zone a new stock of *Lenticulina* appears, represented by Forms D and E. At first Form D (plate 1) occurs sporadically but is extremely abundant in the *obtusum* and *varicostatum* zones. The smooth spire in Form D shows little or no tendency to uncoil. The wall of the test is thick so that, except where sutures tend to be slightly depressed, the are scarcely visible. The radiate aperture occurs on a slight prolongation, but not on a definite neck. No keel is developed.

Form E (plate 2) is abundant and extremely variable, the main trends in variation occurring repeatedly. All variants are compressed, with almost parallel-sided cross sections, approaching the genus *Planularia*. Many other species of *Lenticulina* from different ages follow somewhat similar trends. Form Ea is a small loosely coiled spire consisting of six triangular chambers, which do not overlap one another. The margin of the test is lobulate especially where the sutures are sunken. This form begins to uncoil and forms the basis for all later variants. Form Eb has two or three chambers in a short curvilinear series. In Form Ee the chambers overlap onto the initial portion of the test and are triangular, whereas in Form Eb they are parallel-sided and show no overlap.

In Form Ec an early stage similar to Form Ee is followed by a smaller end chamber, showing no overlap. Form Ed carries this tendency further, but the whole test is broader than in Form Ec.

After the early tendency for the chambers to overlap in Form Ec, Form Ef and finally Form Eh have parallel-sided chambers with no overlap and an almost straight apertural margin. In Form Ef the latter part of the test broadens, and the sides diverge. However, Form Eh shows a complete break in growth after this stage is reached, with a series of chambers greatly reduced in breadth. This gives the appearance of "rejuvenation" so often seen in other members of the Lagenidae.

In the broad curvilinear Form Eg the end chambers become irregular chevron-shaped, and are asymmetrical. This abortive offshoot does not grade into any true forms of "*Flabellina*". All the apertures in the specimens of Form E are radiate or radiate-crenulate, flush with the test or on a small protruding neck.

During their long ranges Forms D and E give rise to many variants but, although the trends of Form E are often repeated at certain horizons, only a few of the variants occur. There does not appear to be any direction in the evolution of this group.

In the lower *raricostatum* zone Form D occurs with rare specimens of Form E. A very variable group of Form F (plate 2), probably derived from Form D, predominates from the *raricostatum* to *ibex* zones.

Little or no significant variation occurs in Form Fa, a small form representing the early stage of all other variants of this group, the main differences occurring in the uncoiled portion of the tests.

Form Fa is a small nautiliform spire, with few chambers to the whorl. The test is smooth or with slightly depressed sutures. The initial part of the test is covered by a pseudo-boss formed by a thickening of the wall. The radiate aperture is on a prolonged thick neck. Uncoiling takes place in the later part of the test in Form Fb. After an initial spire two chambers are added, one triangular, the other parallel-sided. Although the end-chamber shows considerable variation, it is usually circular in cross-section.

Form Fc uncoils still further until a rectilinear series of parallel-sided chambers develops. The end and penultimate chambers often decrease in size, the sutures becoming constricted and the periphery lobulate. The end chamber is drawn out towards the thick apertural neck.

Form Fe is similar to Form Fb, except that a further small chamber is added, giving the appearance of a distinct break in the normal growth rate.

Forms Fc and Fe belong to a distinct group of variants with lobulate peripheries and constricted chambers; separated from Forms Fd and Fg in which the margins of the test are smooth, and the sutures only slightly constricted. The general tendency for the later chambers to broaden in both Forms Fd and Fg is important. There is a tendency in some variants for the chambers to broaden in early growth stages so that in Form Fg the initial spire appears to be included in the test which becomes almost parallel-sided (except near the end-chambers).

In the Form Ff a relatively small initial spire is followed by chambers which broaden rapidly so that the increase in volume of later chambers is extremely large. The apertural margin, which is usually straight, tends to become slightly S-shaped in Forms Fd and Fg.

All the variants within this group do not occur at each horizon. At higher levels in the *raricostatum* zone the rectilinear portion of the test becomes greatly elongated, a tendency which is coupled with a decrease in the size of the initial spire, giving rise to Form Fg. Form G (plate 3) is probably derived from Form F. The breadth of the chambers is reduced, and the uncoiled portion of the test lengthened. Two forms are abundant; Form Ga, having a small spire followed by a rectilinear series of eight to ten parallel-sided chambers, with the end-chamber often elongated, and having a long apertural neck. Later sutures are constricted, giving rise to a lobulate periphery.

Form Gb differs from Form Ga in the later development of the rectilinear series of chambers, a strong curvilinear series occurring first. Good examples of Form F (plate 3) occur at later horizons in the *raricostatum* zone, clearly demonstrating a tendency often seen in species of the genus *Lenticulina*; namely for the usual nautiliform coil to become slightly eccentric. If they were not connected by a series of gradations to the normal forms of *Lenticulina*, some specimens (plate 3, figs. 3, 4, 5) could be placed in the "genus" *Darbyella*.

Form H (plate 3) first occurs in the *jamesoni* zone, but maximum variation is found in the *ibex* zone. The spire consists of a few chambers loosely coiled, often with a central thickening of the wall over the umbilicus. A strong keel develops, and the sutures are slightly raised. Except for slight modifications variation is similar to that exhibited in other groups.

Form Ha uncoils, the keel disappears, the chambers reduce in size, and the ribs along the sutures are only present on the spire. Over the umbilicus boss

the ribs are impersistent, resulting in an irregular ornament. Form Hb is similar to Form Ha except for the development of a rectilinear portion with constricted sutures. Over the area in the vicinity of these sutures extremely faint striations occur and are oblique to the direction of the sutures.

Similar fine striations occur on some species of otherwise smooth forms belonging to the genus *Dentalina*.

In both Forms Ha and Hb the radiate aperture is on a well developed apertural neck. Some chambers become chevron-shaped in the *davoei* zone, and this trend continues into and is more pronounced in the middle and upper Lias.

Form I is extremely common in both the upper part of the lower Lias and the middle Lias. It consists of a loose initial coil, with no keel, followed by either a rectilinear or curvilinear part of the test. This later portion of the test often shows either an irregular series of end-chambers, or a regular increase or decrease in the breadth of the test.

Usually the sutures are clearly visible through the white or brown test.

At some horizons conditions appear to have affected the growth, for grotesque, large and twisted tests predominate.

ANALOGIES

As with the ammonites, apparently disconnected stocks of *Lenticulina* appear quite suddenly, become widespread and finally die out only to be replaced by further groups. In both the ammonites and oysters similar morphological types and trends in variation are repeated in various stocks giving rise, in some cases, to heterochronous homeomorphy.

The main stocks of *Lenticulina* appear at about the same time in both England and the rest of Europe, and it would be difficult to establish either their source of migration or evolution. As already stated the stocks often appear to be disconnected from each other, and direct ancestry is not easily determined.

TAXONOMY

Because of the wide variation occurring in a few characters within the species of Liassic *Lenticulinae*, and the amount of homeomorphy present between unrelated forms, it is difficult to assign a form to an earlier described species. The task is rendered still more difficult unless one is able to see type specimens, and to ascertain their accurate horizons.

In view of the last statement a full synonymy of each form will not be attempted, only the more important previous works will be discussed, and an attempt will be made to assign the main groups to earlier described species.

PREVIOUS WORK

Where possible the Form will be compared with earlier species, bearing in mind their stratigraphical horizon.

The most comprehensive work on the Lias foraminifera is by Bartenstein and Brand (1937):

Planorbis zone

Form A = ?*Cristellaria* (L.) *varians* (Bornemann), pl. 1.A, fig. 18.

Angulatum zone

Form B = *Cristellaria* (L.) *minuta* Bornemann, pl. 2.A, fig. 18a.

= *Cristellaria* (L.) *crepidula* (Fichtel and Moll), pl. 2.A, fig. 18b.

Form B = *Cristellaria* (L.) *minuta* Bornemann, pl. 2.B, fig. 31.

Form C = *Cristellaria* (L.) *varians* (Bornemann) form *b*, Bartenstein and Brand, pl. 2.B, fig. 32.

Lias β (*raricostatum*, *bifer*, *planicosta* zones)

Form C = *Cristellaria* (L.) *varians* (Bornemann) form *a*, Bartenstein and Brand, pl. 3, fig. 32.

Form F = *Cristellaria* (A.) *vetusta* d'Orbigny, pl. 3, fig. 43 a, b.

Form F = *Cristellaria* (A.) *prima* d'Orbigny, pl. 3, fig. 44.

Lias γ (*capricornu* = *davoei*, *centaurus* = *ibex*, *jamesoni* = *jamesoni* zones)

Form Ga = *Cristellaria* (A.) *rectalonga* n. nov. Bartenstein and Brand, pl. 4, fig. 80.

Form F = *Cristellaria* (A.) *matutina* d'Orbigny, pl. 4, fig. 79.

Form F (young) = *Cristellaria* (L.) *muensteri* (Roemer), pl. 4, fig. 69a, b, c.

Previous work done by Franke (1936):

Lias α *angulatum* beds)

Form A = *Cristellaria* (L.) *convoluta* Bornemann, pl. 11, fig. 14.

Lias δ and middle Lias

Form F = *Cristellaria* (A.) *matutina* d'Orbigny, pl. 10, figs. 11, 12.

= *Cristellaria* (A.) *vetusta* d'Orbigny, pl. 10, fig. 13.

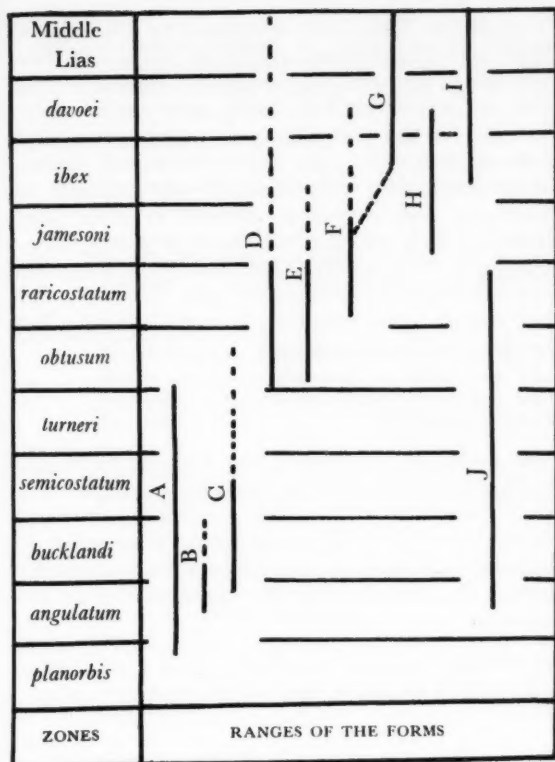
Lias γ

Form H = *Cristellaria* (L.) *varians* Bornemann forma *suturalis* - *costata* Franke, pl. 11, fig. 13.

Lias δ and middle Lias

Form Ga = *Cristellaria* (A.) *antiquata* d'Orbigny, pl. 10, fig. 14.

LENTICULINA OF ENGLISH LIAS



TEXT-FIGURE 1

Since this present work was prepared Norvang (1957) has published an important contribution on foraminifera from the Lias of Denmark. In this work the major evolution of three lineages of smooth lenticulinids is discussed.

Prominence is given to the degree of coiling, and it is inferred that later species have a higher degree of coiling in the initial part of the test. As a general statement this is correct, but I have not been able to find any progressive change but only abrupt changes within the coiling of each species.

Variation in the coiling between different morphological shapes occurs, as would be expected, but if one group is selected there appears to be no progressive variation towards a higher degree of coiling. Norvang (p. 119) produces a diagram of the "Evolution of *Marginulinopsis matutina* (d'Orbigny) supergroup", and discusses this problem. The present author would not agree that *Vaginulina listi* (Bornemann) is at all connected with *Saracenaria sublaevis* Franke and *Saracenaria hannoverana* Franke. It may well be that *Vaginulina listi* (Bornemann) is related to some other species group belonging to

Dentalina, and that the two species of *Saracenaria* are derived as direct variants from forms belonging to the *Lenticulina gottinensis* (Bornemann) plexus. Many species of *Lenticulina* from both the Jurassic and Cretaceous show a tendency to become triangular in cross-section approaching *Saracenaria* often progressing still further by reducing the spire until a stage is almost reached when a *Saracenella* results.

Lenticulina varians (Bornemann)

Abundant specimens of *Lenticulina varians* (Bornemann) form one of the two major groups of lenticulinids from the upper Lias.

The author (1950b) has already briefly indicated the variation in this group, but a detailed examination of the flabelline-stage was not previously attempted. Attention was drawn (1950b, p. 9) to the passage that exists between lenticuline and flabelline varieties. Tappan (1956) doubts the existence of this gradation. Bartenstein (1950) has shown, from other formations, that this type of gradation or variation does exist.

Variation in the lenticuline forms (plates 6, 7) is shown in the different ways in which uncoiling of the spire takes place, coupled with the degree of overlap of later chambers onto the initial portion of the test.

The two chief variants are: one, with an uncoiled curvilinear series of chambers with no overlap, and the other, having an uncoiled portion loosely in contact with, or just separated from the initial coil, the chambers overlapping onto the initial portion of the test. There is a tendency for later chambers to become swollen in the first group, and slightly compressed in the second, this latter giving rise to tests with chevron-shaped chambers.

The final variable shape of the flabelline-test depends mainly on two factors; first, the position of the initial spire in relation to the remainder of the test, and second, to the development of the chevrons, which may be irregular asymmetrical or symmetrical. Usually there are four or less chevron-shaped chambers forming the test, but rarely up to six.

Selected variants are shown on plate 6. Figure 1 shows the common regular initial spire, with chambers overlapping onto the proloculum. From this form all other variants were derived it, being present in all forms as the initial stages of the test.

An early stage in the development of chevrons is shown in figure 2, where only two such chambers are present, with arms of equal length, giving rise

to a symmetrical test. This stage is carried further with five chevrons developed in figure 3.

Figure 4 has six regular chevron-shaped chambers. The last chamber of the spire is much smaller than usual and does not overlap onto the initial coil. In order to compensate for this irregularity the next chamber, although a chevron, is asymmetrical with one arm reaching to the proloculum, the other being short only overlapping the last chamber of the spire.

The initial coil may be broadened and succeeded by one chevron with almost equal arms as shown in figure 5.

Figure 6 shows uncoiling before the chevrons are added. Two symmetrical chevron-shaped chambers with almost equal arms are formed, but the end-chamber is smaller than the penultimate.

Three large, symmetrical chevron-shaped chambers succeed one enlarged uncoiled portion in figure 7, a distinct break in the growth rate however gives an irregular periphery.

Only a slight tendency towards chevrons is developed in figure 8, where the initial stage is enlarged, and is followed by two asymmetrical chambers, one arm of which is poorly developed. This is carried further and the chevrons better developed in figure 9.

Lenticulina inaequistriata (Terquem)

Variation takes place in the number, position and strength of the ribs. Although the amount of variation is often great, the general trends are of stratigraphical use. In the basal *angulatum* zone two main forms occur, one with an almost triangular shaped test, and the other with an uncoiling test which becomes parallel-sided. The ribs on the former may be divided into two different groups; first about three strong ribs, parallel to the apertural margin of the test, and a second group of weak irregular ribs. The latter group sometimes bifurcate or are interrupted in growth. They occur over most of the test until finally disappearing on the end-chamber. On the other form the ornament is even more irregular, only two strong costae and about four weak bifurcating ribs occur.

At higher levels in the *angulatum* zone, the ribs are stronger, more numerous, and usually only one set occurs, crossing the test at an angle to the apertural margin. The shapes of the tests are similar to those from earlier beds, except in forms with parallel sided tests, where the uncoiled portion is larger. A variable keel is sometimes developed in early stages of the test.

Two distinct forms have developed by the *bucklandi* zone, one a large broad triangular form, with thin well-developed ribs, meandering irregularly over the test, sometimes bifurcating, and finally disappearing on the end-chambers; and another form with an oval test, tightly coiled, irregularly keeled, with few strong ribs showing no tendency to bifurcate, and extending parallel to each other from the early stages of the test until finally disappearing on the end-chamber. Both these forms are abundant until the *semicostatum* zone. In this zone the last two or three chambers become smooth. The species then becomes extinct.

ACKNOWLEDGMENTS

The author is indebted to the directors of H. M. Geological Survey for permission to publish this report based on material from a borehole at Stowell Park, Northleach, Gloucestershire. The author is grateful to Dr. W. D. Macfadyen for reading the manuscript, and for helpful suggestion during the research.

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EXPLANATION OF PLATES

THE LOCALITIES ARE ALL IN STOWELL PARK, NORTHLEACH, GLOUCESTERSHIRE, EXCEPT WHERE OTHERWISE INDICATED.

PLATE 1

- 1-7 Form A - Lower Lias *angulatum*-zone
1-6, 1940-1950 feet; 7, 1920-1930 feet. Showing
the chief variants.
- 8-10 Form B - Lower Lias *angulatum*-zone
1940-1950 feet.
- 11-11 Form C - Lower Lias *angulatum*-zone
1920-1930 feet. Showing the tendency to uncoil
or produce a few chevron-shaped chambers.
The development of the keel and the crescentic
boss is seen.
- 14 Form D - Lower Lias *obtusum*-zone
1500-1510 feet.

PLATE 2

- 1-8 Form E - Lower Lias *obtusum*-zone
1500-1510 feet. Showing the overlap of the
chambers, uncoiling to a curvilinear or rectilin-
ear series in the chief variants.
- 1-15 Form F - Lower Lias *varicostatum*-zone
1390-1400 feet. Showing the various uncoiled
tests, some with reduced spires.

PLATE 3

- 1-2 Form G - Lower Lias *varicostatum*-zone
1380-1390 feet. Showing the extremely narrow
tests developed in this form.
- 3-5 Form F - Lower Lias *varicostatum*-zone
1300-1310 feet. This species shows a tendency to
eccentric coiling, a feature common to many
species of *Lenticulina* usually separated into the
"genus" *Darbyella*.
- 6-7 Form H - Lower Lias *ibex*-zone
1110-1120 feet. Showing the keel and raised
ribs developed in the early part of the test,
striations appear along the sutures in the uncoil-
ed form.
- 8-10 Form I - Lower Lias *davoei*-zone
1000-1010 feet.

PLATE 4

- 1-6 Form A - Lower Lias *angulatum*-zone
Mik (M) 460.001-006
1940-1950 feet.
- 7 Form C - Lower Lias *angulatum*-zone
Mik (M) 460.007
1920-1930 feet.

- 8-13 Form B - Lower Lias *angulatum*-zone
Mik (M) 460.118-013
1940-1950 feet.

- 14-17 *Lenticulina inaequistriata* (Terquem)
Mik (M) 460.014-017
Lower Lias.

- 18-21 *Lenticulina varians* (Bornemann)
Upper Lias *serpentinum*-zone. Byfield, North-
amptonshire. Showing the external views of four
specimens with different development of the
chevron-shaped chambers.

PLATE 5

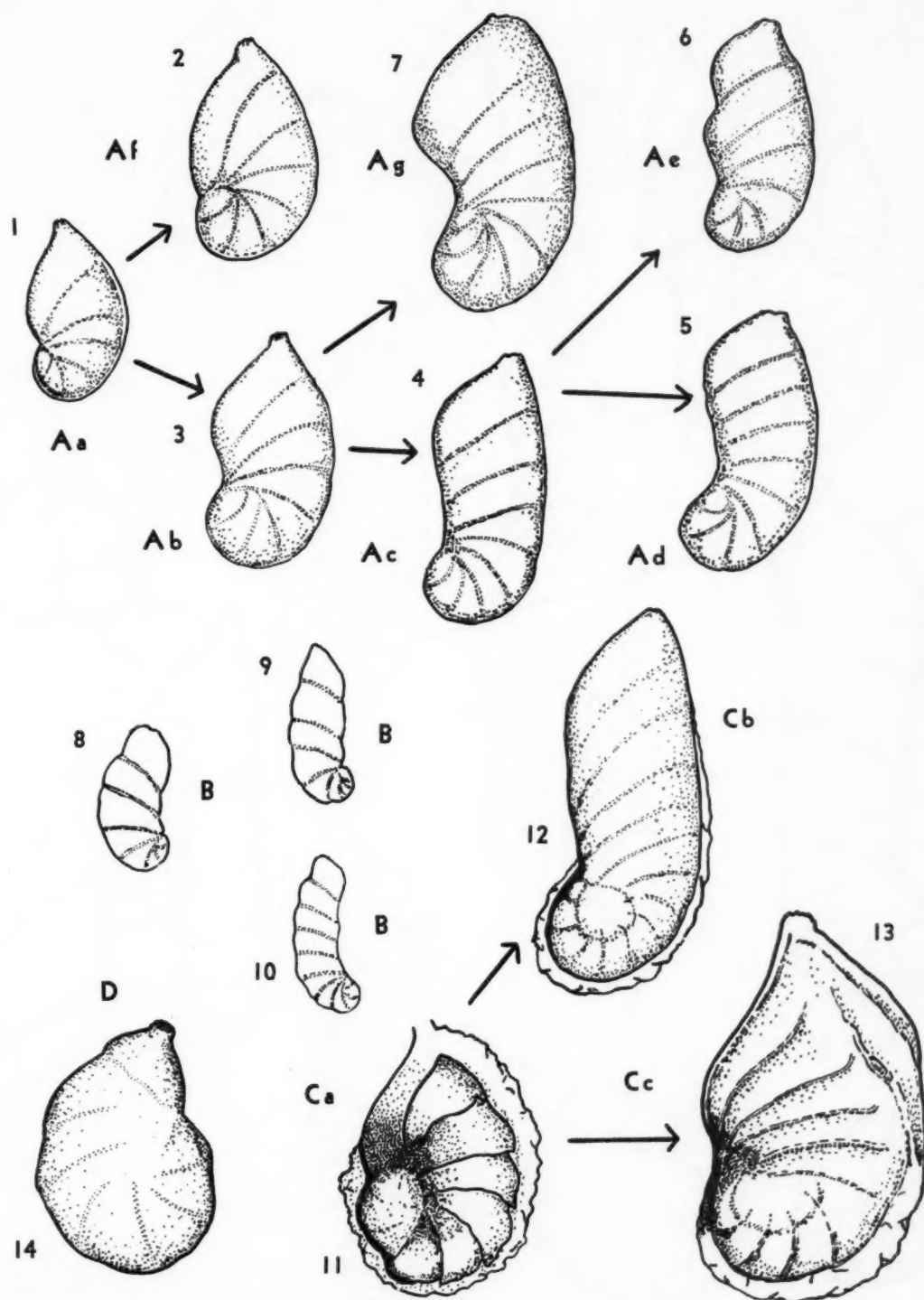
- 1-6 Form F - Lower Lias *varicostatum*-zone
Mik (M) 460.018-023, Mik (M) 460.024-027
1390-1400 feet.
- 7-10 Form I - Lower Lias *davoei*-zone
Mik (M) 460.024-027
1000-1010 feet.
- 11-13 Form E - Lower Lias *obtusum*-zone
Mik (M) 460.028-030
1500-1520 feet.
- 14 Form H - Lower Lias *ibex*-zone
Mik (M) 460.031
1390-1400 feet.
- 15 Form F - Lower Lias *varicostatum*-zone
Mik (M) 460.032
1390-1400 feet.
- 16 Form G - Lower Lias *varicostatum*-zone
Mik (M) 461.001
1380-1390 feet.

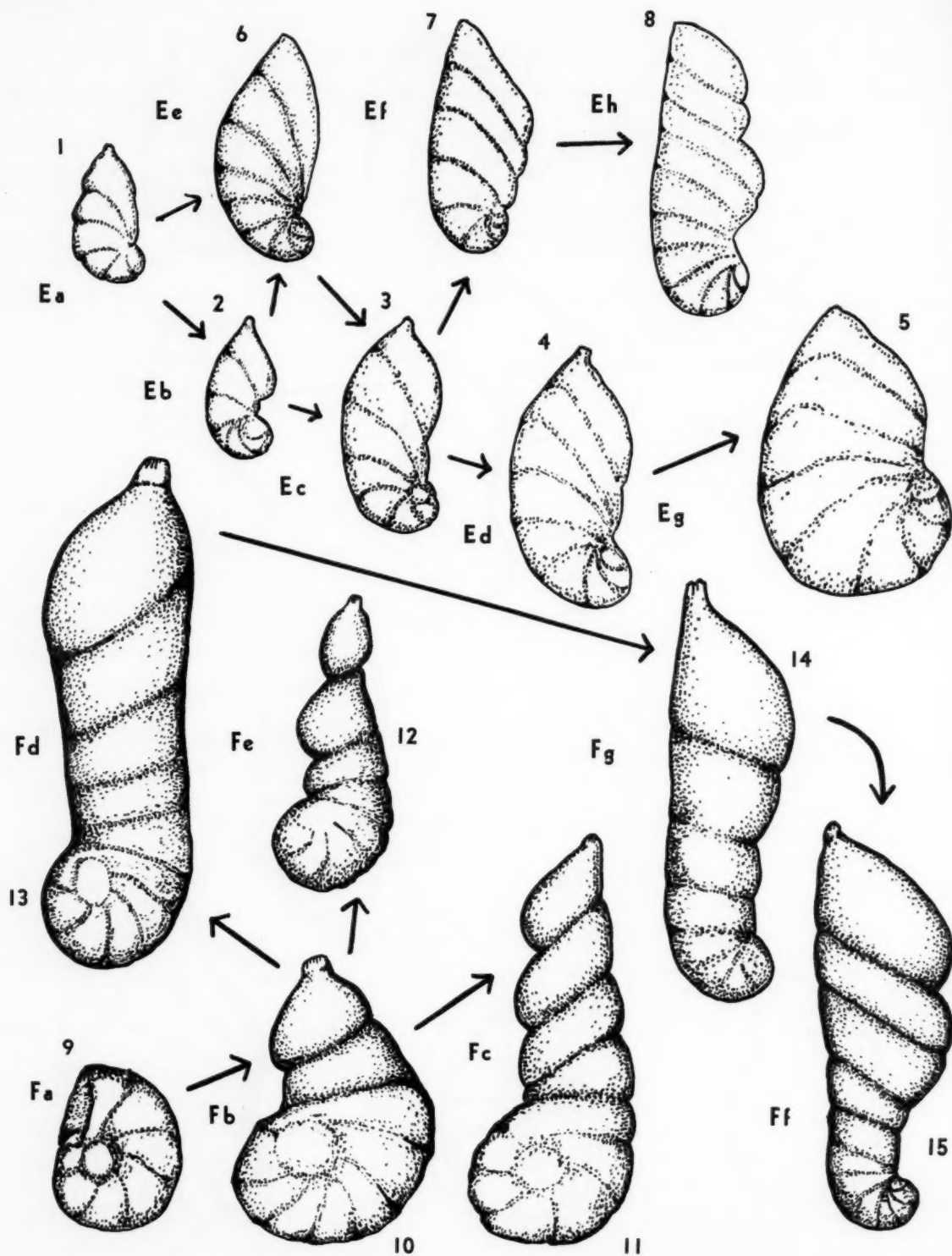
PLATE 6

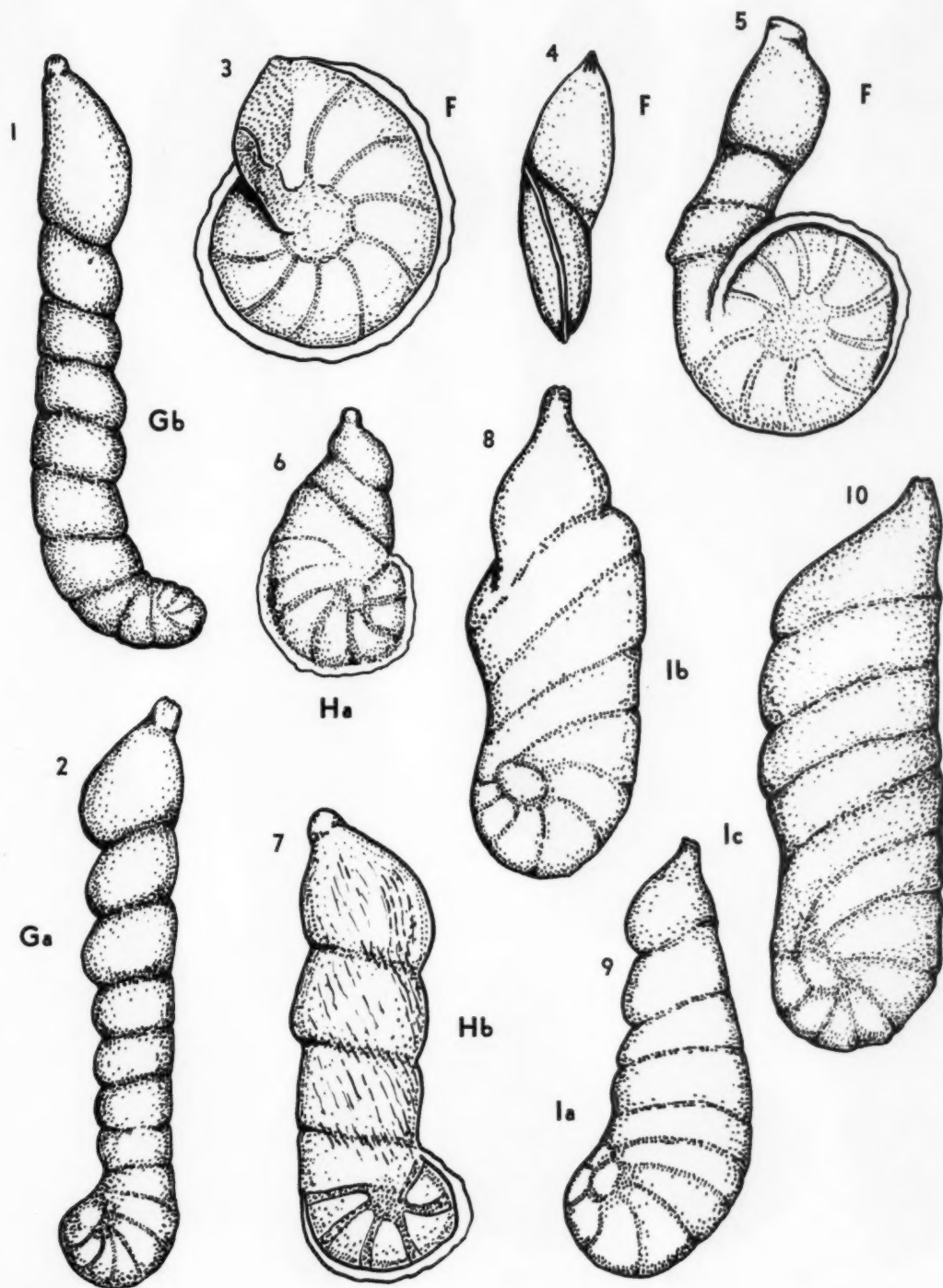
- 1-9 *Lenticulina varians* (Bornemann)
Upper Lias *serpentinum*-zone. Byfield, Glouces-
tershire. Showing the chief variants with flabel-
line chambers. This is a morphological series,
arranged for convenience of expression, not an
evolutionary series.

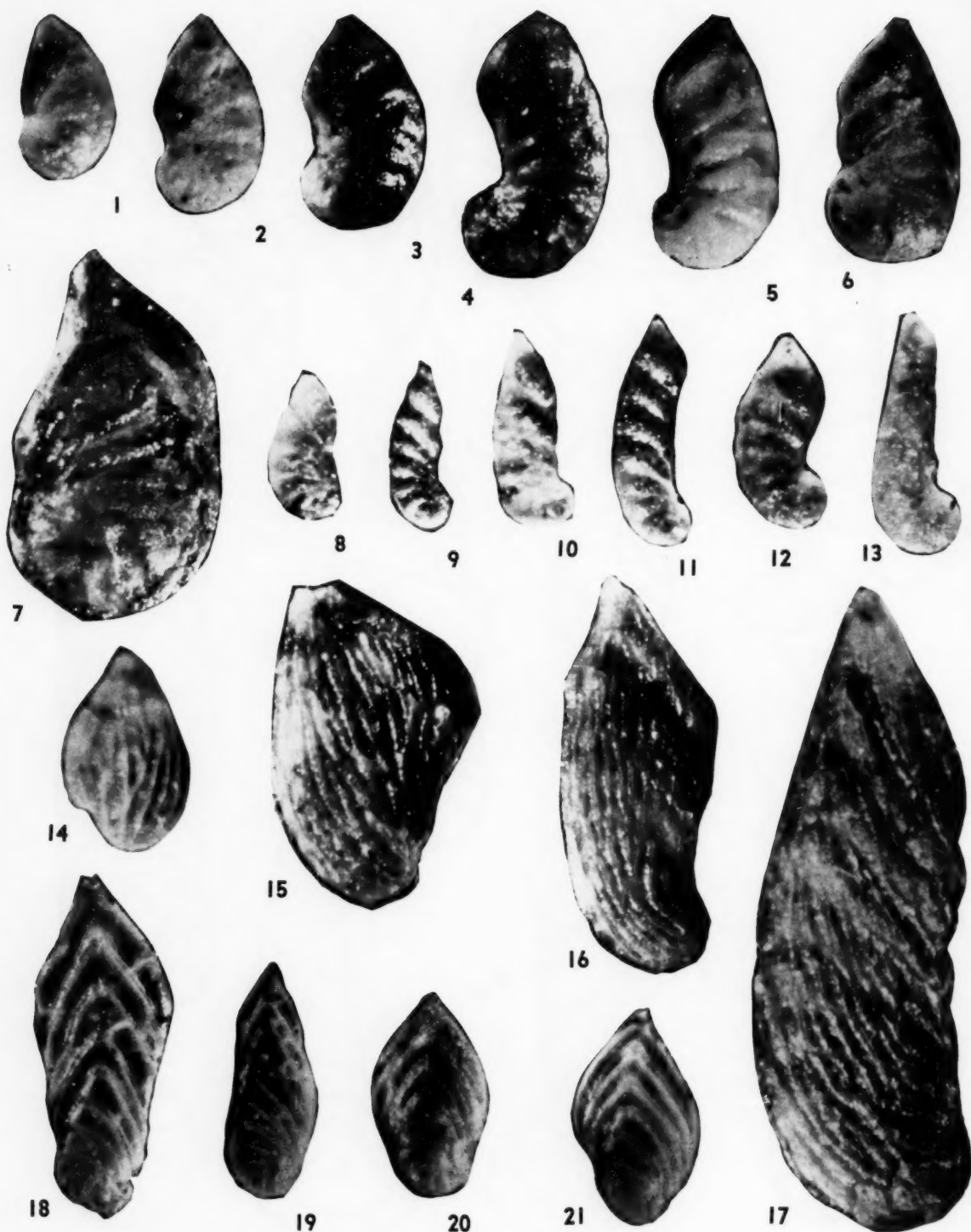
PLATE 7

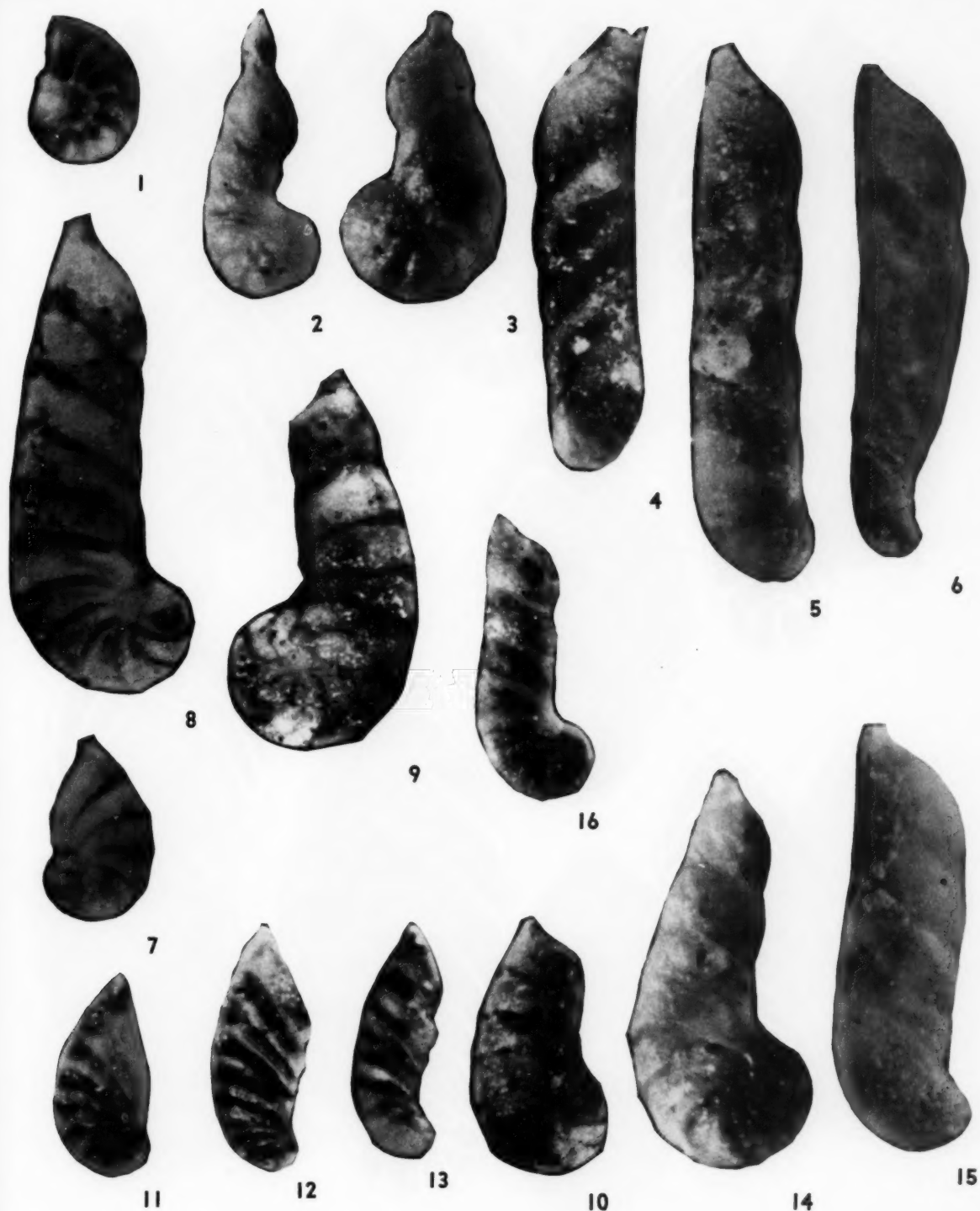
- 1-10 *Lenticulina varians* (Bornemann)
Upper *serpentinum*-zone. Byfield, Northampton-
shire. Photographs by means of transmitted light
to show the arrangement of the chambers, and
the variation of the chevrons.

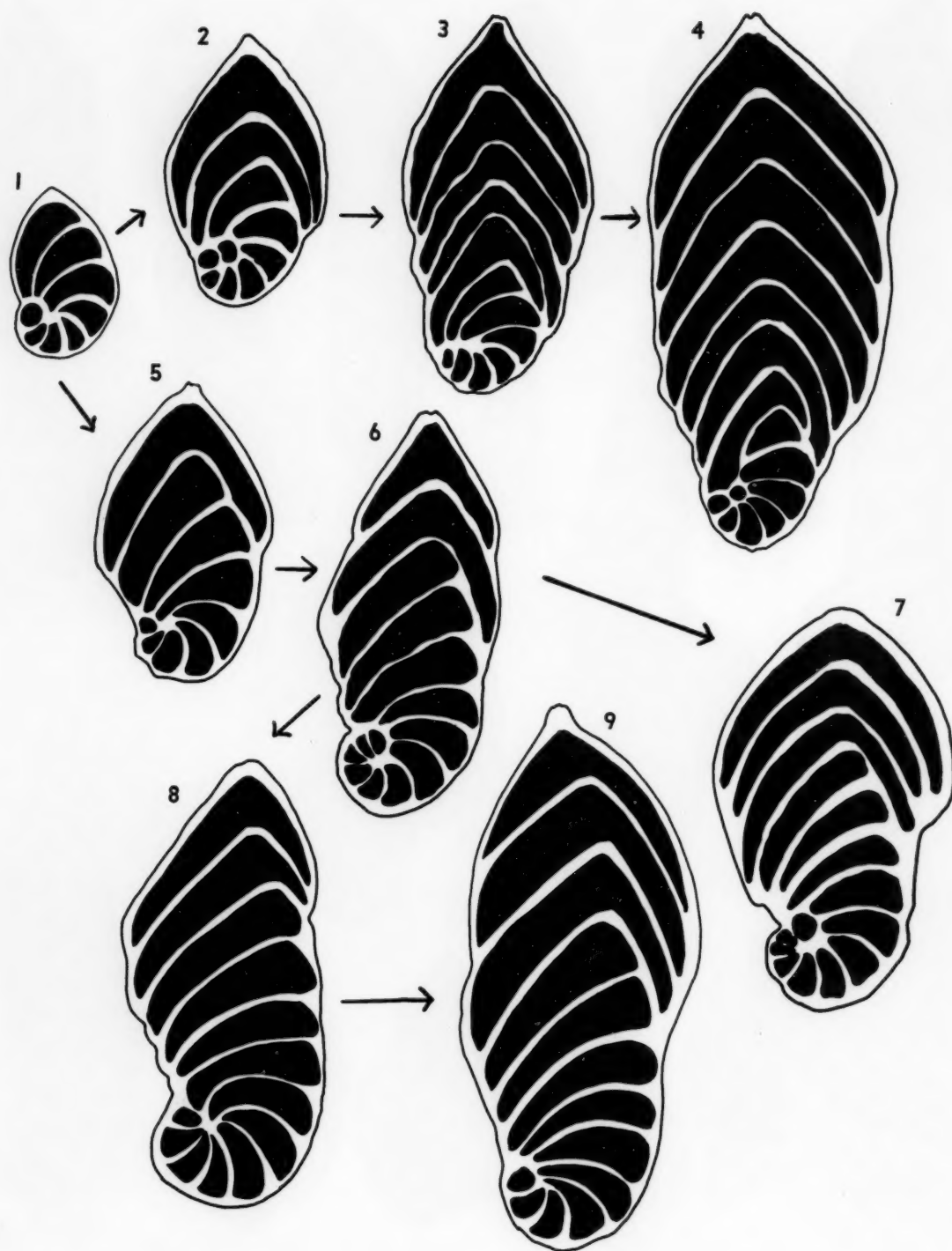
















ABSTRACT: *An investigation of the foraminifera in cores of the bottom sediments of the central Arctic Ocean indicates significant quantitative trends in this relatively uniform environment. Foraminiferal occurrences are compared with sediments, sea-floor topography, water depth, calcium carbonate distribution, organic carbon content of the sediments, temperature and salinity of the water, and associated organisms. A total of 105 species of foraminifera, of which twenty were useful in establishing depth zones, were collected at depths between 433 and 2760 meters. Five species and one variety are new. Faunal changes correspond generally to changes in slope. Application of the data suggests displacement of the sediments in parts of some cores.*

Ecology of some Arctic foraminifera

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INTRODUCTION

An investigation was made to determine the foraminiferal ecology in the central Arctic Basin. In the area studied, the temperature is cold and as near isothermal as in any habitat where foraminifera have been studied.

The material was collected by Mr. Charles Horvath from 1952 through 1955 in three expeditions to the Air Force's floating research station Ice-Island T-3. Numerous published and unpublished reports have been prepared concerning work on Ice-Island T-3 since the United States Air Force first occupied it in 1952. The reader is referred to the work of Knox (1956), Barnard (1956), Crary and Goldstein (1957), and a bibliography compiled by the Air Force Cambridge Research Center, which is complete through June, 1956 (anonymous, 1956).

This study was made possible through financial assistance given by the Shell Development Company, Houston, Texas, and by the United States Air Force to the University of Southern California. The author is indebted to many of the members and associates of the Allan Hancock Foundation for laboratory space, library facilities, encouragement, and assistance throughout the extent of the work. Acknowledgment is especially due Dr. Orville L. Bandy for aid in determination of the species and for many helpful suggestions and guidance in the ecological interpretations and applications of the data. Thanks are due Dr. Kenneth O. Emery for interest and guidance in the sedimentary, oceanographic, and marine geological phases of the study; to Dr. William

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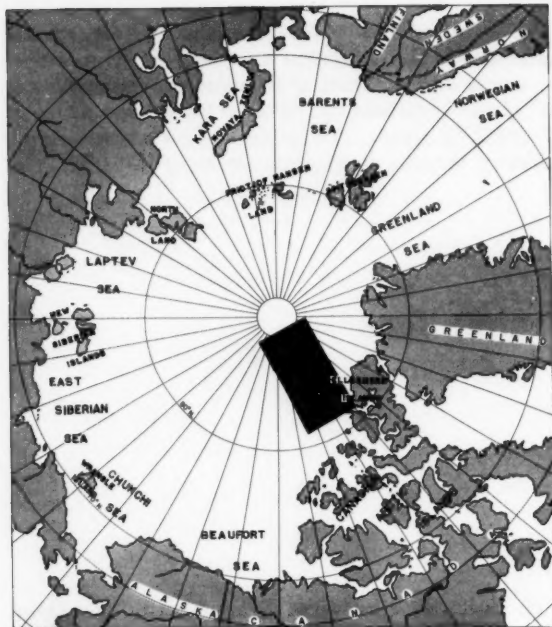
H. Easton for criticism of the manuscript; and Donn Gorsline for the grain-size analyses in the three deepest stations.

Samples were collected from a rectangular area roughly parallel with the northwest coast of Ellesmere Island, bounded by latitudes 82°32' and 86°45' N. and by longitudes 81°20' and 95°40' W. (see text-fig. 1). Samples were taken at depths between 433 and 2760 meters. Surface samples were studied at twenty-four locations to determine biofacies changes within this uniform environment. Twenty samples were studied at ten-centimeter intervals in three cores from depths of 433, 878, and 1710 meters to examine variations in the sequence of deposition.

METHOD OF STUDY

Inasmuch as the cores came from an area presenting many collecting difficulties, attempts were made to obtain as much information as possible from each sample. The information desired included a variety of fields, such as: 1) foraminiferal taxonomy and ecology; 2) sediment characteristics; 3) rates of sedimentation; 4) paleotemperatures; and 5) submarine topography.

The cores were transported to the laboratory from the Ice-Island in three states of preservation: 1) some six-inch segments were put into tin cans and preserved in alcohol; 2) some cores were allowed to dry until firm, then packed with paper and boxed; 3) still other cores were left in the plastic liner of the Phleger corer, alcohol was added, and the plastic



TEXT-FIGURE 1
LOCATION OF THE TRAVERSE OF THE ICE-ISLAND

liner was then sealed with a rubber stopper. Rose bengal was added to the cores that were preserved in alcohol to identify the specimens that were living at the time of collection. This method has been described by Walton (1952). Sediments were analyzed and foraminiferal percentage counts were made for forty-four samples from twenty-four station localities.

The unsegmented cores were halved longitudinally. One half was used for mechanical analysis and foraminiferal determinations; the second half was quartered. The first quarter-section was used for organic-carbon and calcium carbonate analyses. The second quarter was preserved for future studies as specialists become available to work on the material. Stratigraphic studies were made in which segments 2.5 cm. in length were selected at intervals of 10 cm. Twenty-four surface samples were studied for determination of ecologic trends. The samples in the boxes, papers, alcohol, and plastic liners were all treated alike once they had been sectioned and segmented or thoroughly mixed.

With slight modification, the method of mechanical analysis used in this study was that described by Krumbein and Pettijohn (1938, p. 165). The material coarser than 4 phi was dried and sieved in the Ro-Tap Automatic Shaking Machine with Tyler

Standard Screen Scale Sieves, which agree most closely with the Wentworth grade limits. Each fraction of the material coarser than 4 phi received a visual analysis for mineral, rock, and organic content. The fractions were then recombined, and the foraminifera were separated by flotation on carbon tetrachloride. All but two separations were satisfactory. The two cores that did not separate satisfactorily were then recombined with the particulate material, and the entire sample was examined for foraminifera. Of the two samples that did not separate, one was displaced (53-7), but the other appeared to be in place, from a cursory examination of the foraminiferal data (46-2). In sample 46-2, the foraminiferal number (29/gm.) was the lowest of any of those of the Ice-Island stations. The low percentage of material greater than 4 phi and the low foraminiferal number suggest displacement; however, the bathymetric displacement was not appreciable, because foraminiferal percentages agree with those of other samples in the same depth ranges. Percentage counts were made with a typewriter as a counting device. Three cores were selected for stratigraphic studies because of their geographic position, water depth, and length.

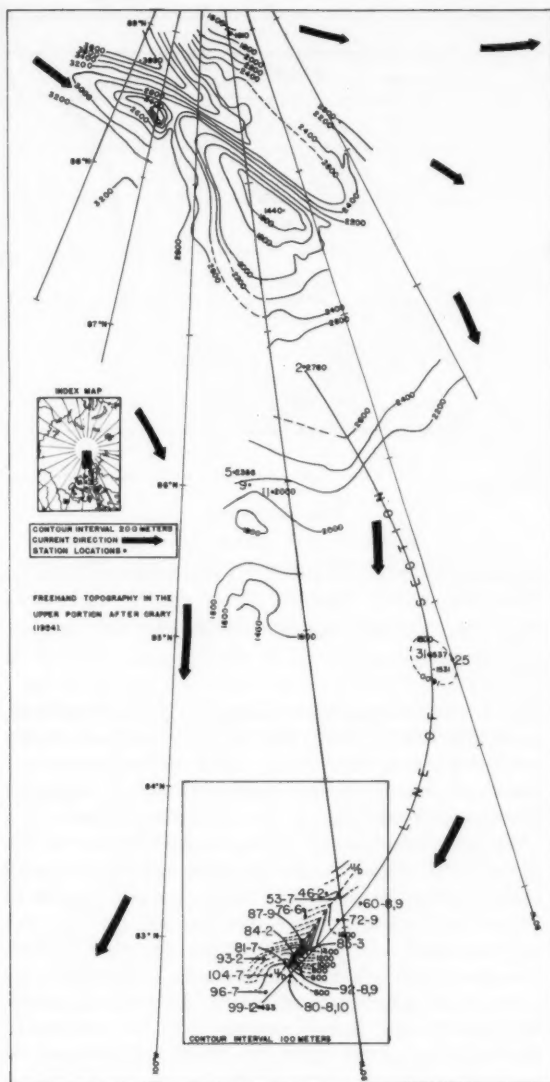
The rose bengal stain was of qualitative value only. The results of the staining must be used with caution because: 1) few foraminifera stained; 2) foraminifera 20 cm. below the surface of the core stained pink; 3) broken and worn foraminiferal fragments have been known to stain (Bandy, personal communication); and 4) some Miocene index foraminifera in California beach sands stain pink with rose bengal (Reiter, 1959). Even with the difficulty encountered in staining foraminifera with rose bengal, however, it is advisable to continue this process until a better method can be devised. The methods of quantitative foraminiferal analysis are patterned after those of Bandy and Arnal (1957).

THE ARCTIC ENVIRONMENT

General

The climatic limits of the Arctic, as defined by Kimble and Good (1955), are those lands "... north of the 50° F. July isotherm or whichever is the warmest month, provided that the mean temperature for the coldest month is not more than 32° F." The limits for the Subarctic are those lands "... where the mean temperature is not higher than 50° F. for more than four months of the year, and where the mean temperature of the coldest month is not more than 32° F." In certain areas the climatic limits of the Arctic extend farther than the margins of the Arctic basin.

ARCTIC FORAMINIFERA



TEXT-FIGURE 2

SUBMARINE TOPOGRAPHY OF A PORTION OF ARCTIC OCEAN

The major landmasses projecting into the Arctic are Greenland, Canada, Alaska, the U.S.S.R., and Scandinavia. There are literally millions of islands bordering on the Arctic Ocean. A few of the larger islands or island complexes are Fridtjof Nansen Land, Novaya Zemlya, North Land, Spitsbergen, Wrangell Island, the New Siberian Islands, and the Canadian Arctic Islands. Eight seas bordering Arctic waters are the Barents, Beaufort, Chukchi, East Siberian, Greenland, Kara, Laptev, and Norwegian Seas (see text-fig. 1). The sea-floor topography in

the Arctic Ocean is still little known. Recent Russian, French, and United States expeditions have added greatly to extant knowledge (Saks and others, 1957).

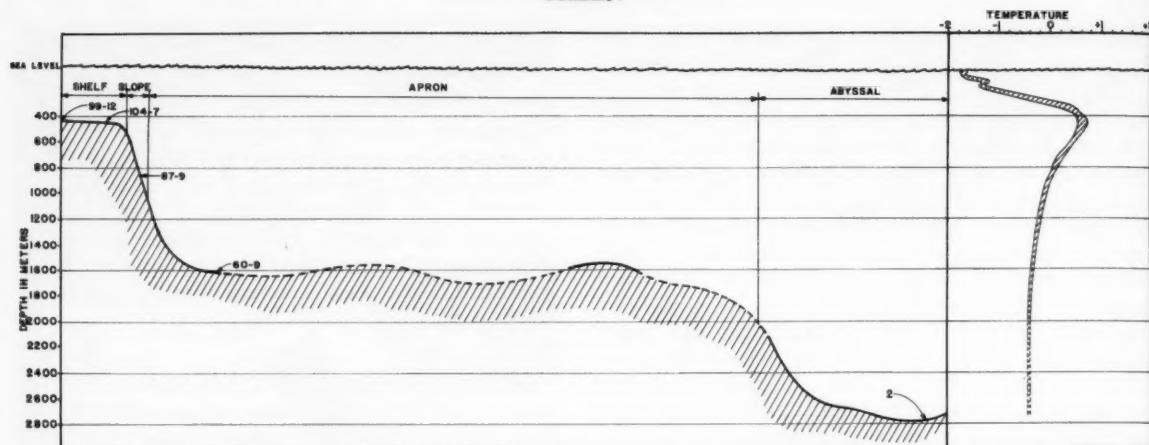
Circulation patterns in the Arctic Ocean are considerably more complex than was first supposed by Nansen (1902). Worthington (1953) found an anticyclonic eddy operating north of Alaska in the Beaufort Sea. Shirshov (1944) indicated surface currents flowing in an easterly direction off the coast of Siberia, with a countercurrent flowing farther offshore.

Sea-floor topography

The path of movement of the Ice-Island in 1952 was over a portion of the submarine Lomonosov Mountain Range. This range appears to be structurally controlled, on the basis of seismic evidence (Emery, 1949) and of trends in the physiographic features. The crest of the range is thought to extend across the Arctic Ocean from the East Siberian Sea to the Ellesmere Islands (see text-fig. 2) (Ostrekheim, 1954). The deepest core station was located in what appears to be a canyon. The hummocky area shown in the profile (text-fig. 3) is largely hypothetical, based on fairly numerous soundings which indicate that the depth is only slightly irregular. The hummocky area appears to be a part of the sedimentary apron. From the profile shown in text-figure 2, and the few evidences of displacement of the sediment, the continental slope near Ellesmere Island appears to be in the youthful stage, as that term is used by Dietz (1952). The continental slope has a declivity of about $2\frac{1}{2}$ per cent and lies between 500 and 1500 meters. The continental shelf is extremely flat, with only a slight upward inclination onshore. Horvath reported (personal communication) during the 1955 expedition that there was a rapid change of depth at what now appears to be a fault on the continental slope. Several cores were attempted without success on the steeply sloping fault(?) face. When a core was finally obtained from the submarine talus area, it proved to be the longest core taken (38 inches). This core was filled with rock fragments to such an extent that it approached a deep-water breccia. Much of the rock material did not appear in the other cores, indicating that the pebbles and granules came from the fault(?) face.

Oceanography

An excellent review of the general oceanography of the Arctic Basin has been given by Worthington (1953a). Detailed information concerning oceanographic observations made from Ice-Island T-3 and the oceanographic results of project Skjupump I and Skjupump II are also the work of Worthington (1953a, b).



TEXT-FIGURE 3
SECTION (2)-(99-12)

Worthington found that the temperatures vary between -1.70°C . and $+0.58^{\circ}\text{C}$. In the depth of water in which the core samples were taken, the temperature range was less than 1°C . ($+0.52^{\circ}\text{C}$. at 444 meters to -0.41°C . at 2164 meters); thus the temperature is almost isothermal from top to bottom. The temperature curve crosses the boundary between positive and negative temperatures at approximately 1000 meters. According to Worthington, the shape of the temperature curve is little affected by seasonal changes at the surface, but is influenced more by the circulation of Atlantic waters into the Arctic Ocean. At depths below 500 meters, the salinity remains quite constant between 34.70 parts per thousand and 34.99 parts per thousand for all Ice-Island and Ski-jump stations. The salinity of the surface water is much reduced because of the influx of fresh water, primarily from landmasses surrounding the Arctic Ocean and secondarily from melting snow.

Because of the melting of the ice pack during the summer months, the ice is appreciably thinner. This allows greater penetration of light into the ocean during the summer months, with a subsequent increase in the phytoplankton, followed by a rise in the amount of zooplankton (Shirshov, 1944).

The surface currents of the Beaufort Sea, as indicated by the 600 decibar surface, form a clockwise eddy (Worthington, 1953). A current meter was lowered through the ice during the Ice-Island expedition, encountering no measurable counter or cross currents in depth (Horvath, personal communication). This fact, plus the deep-temperature data, indicate that "... the Beaufort Sea eddy extends in depth to the

neighborhood of 2000 meters" (Worthington, 1953b). Thus the surface currents shown on Worthington's map may also indicate deep-water circulation.

Sediments

The Arctic sediments were found to be poorly sorted, generally fine-grained, silty sandy clays and clayey sandy silts (see text-fig. 4). The sediments coarser than very fine sand were examined with a binocular microscope to determine the important constituents of the coarse fraction and also to see whether or not separations of the coarse fractions would be useful in this study. The following results were obtained: 1) 75 per cent of the coarse fraction was quartz, and approximately 10 per cent of the quartz had high roundness and sphericity and was frosted, indicating a second or third-cycle sediment, whereas the rest of the quartz was poorly rounded; 2) 15 per cent of the coarse fraction consisted primarily of basic igneous and metamorphic rocks, with some andesites, granites, limestones, and sandstones present; 3) 10 per cent comprised miscellaneous mineral and organic debris, among which olivine, hornblende, pyroxene, mica, and glauconite(?) were common minerals.

The abundant material greater than -2ϕ on the slope area (see text-fig. 5) created an apparently anomalous situation, inasmuch as the shelf, being nearest to the shore, would be expected to receive more of the coarse material from ice-rafting than the slope. Erosion from the fault(?) or fault zone(?) on the slope is thought to account for the higher percentage of coarse material on the slope. Sorting on the slope becomes poorer because of the high percentage of coarse material.

ARCTIC FORAMINIFERA

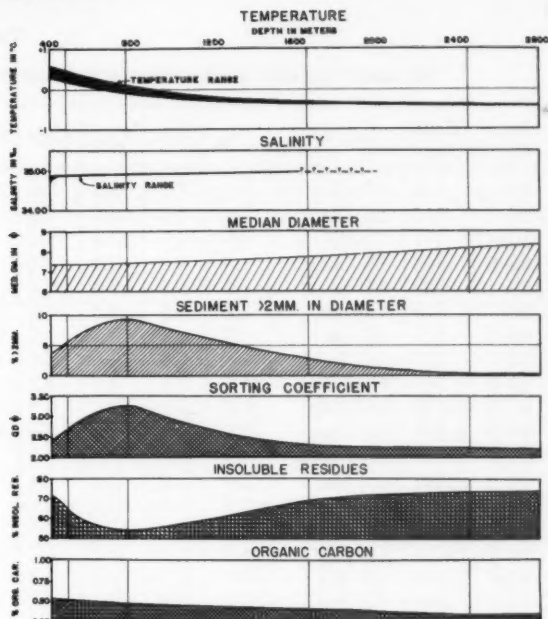


TEXT-FIGURE 4

DIAGRAM SHOWING RELATIVE PROPORTIONS OF SAND, SILT, AND CLAY IN SOME ARCTIC SEDIMENTS

Among the ice-rafted materials in core 87-9 (lat. 82°54' N., long. 92°45' W'), a limestone fragment containing several individuals of *Profusulinella*(?) sp. was found 70 cm. below the surface of the core. The limestone fragment did not come from the fault in the area of station 87-9, inasmuch as it was a broken fragment from a well rounded, glacially striated pebble. *Profusulinella* is commonly found in rocks of Moscovian or lower middle Pennsylvanian age and is considered one of the best index fossils (Thompson, 1948) of this age. With increased paleontological information on the areas surrounding the Arctic Basin, a better understanding of the source of the sediment may be gained. Blackadar (1953) does not mention fusulinid-bearing limestones from the northern coast of Ellesmere Island. Three references to fusulinid foraminifera in the Arctic are: 1) Goës (1883), a paper on *Fusulina cylindrica* Fischer from Spitsbergen; 2) Staff and Wedekind (1910), a paper on Spitsbergen fusulines; and 3) Rauzer-Chernousova (1936), a brief summary of the stratigraphic distribution of foraminifera in the upper Paleozoic of Asia, as well as America and Europe, based on Russian material. *Profusulinella* was included in Rauzer-Chernousova's discussion of fusuline types.

Digestion of the soluble material in a solution of dilute hydrochloric acid (four parts water to one part acid) indicated an average of 40 per cent soluble materials (Table 1). The highest average percentage of acid-soluble material was found on the slope. Values for individual stations vary widely; nevertheless, the averages for the shelf, slope, apron, and



TEXT-FIGURE 5

TRENDS IN THE PHYSICAL AND CHEMICAL CHARACTERISTICS

abyssal zones show an increase on the slope and then a decrease into deeper water (see text-fig. 5). On visual analysis, the calcium carbonate content of the sediment appeared to be about half of the 40 per cent found by digestion in acid. It is difficult, however, to approximate the calcium carbonate percentages from visual analysis. Emery, Gorsline, Uchupi, and Terry (1957) found an average error of 12 per cent with this method. Much of the soluble material may occur in the silt and clay-sized materials, which may account for the apparent high percentage obtained with hydrochloric acid digestion.

Organic carbons were low, generally between 0.21 and 0.84 per cent; however, one sample had 1.06 per cent organic carbon (text-fig. 5). The high value was not used in determining average values, since it does not agree statistically with the rest of the results. Organic contributions to the sediments are low probably because of the low bio-mass in the Arctic Ocean. Much of the organic material is recycled before it reaches the bottom.

The low percentage of organic carbon, the high percentage of soluble material, the poor sorting, and the median diameter of these sediments seem to compare closely with *Globigerina* ooze from the California coast (Emery, 1954).

GREEN

TABLE 1

SEDIMENT PARAMETERS AND FORAMINIFERAL DATA FOR SOME SEDIMENTS FROM THE ARCTIC BASIN

Sta. No.	Dpth (m.)	Sed. type	Q ₂₅	Md	Q ₇₅	Grvl	Sand	Silt	Clay	QD	% Sol.	% Org. Carbon	FN ^a	NS ^b	NG ^c
99-12	433	CS Silt	5.1	7.1	8.9	3.6	17.1	41.0	38.3	1.90	36.7	0.41	12,300	31	20
96-7	445	SS Clay	5.4	7.6	10.9	5.2	8.9	40.8	45.1	2.75	42.1	0.55	3,060	23	18
104-7	497	CS Silt	4.9	8.5	10.6	5.5	9.6	44.1	40.8	2.85	No Data		119	28	21
80-8	500	SS Clay	4.3	6.4	8.9	2.4	17.3	56.1	24.2	2.30	29.2	0.82	214	43	18
80-10	500	SC Sand	1.5	6.8	9.3	10.7	26.8	27.9	34.6	3.90	35.5	0.47	70	37	21
81-7	510	CS Silt	4.8	6.8	9.5	4.9	10.6	49.0	35.5	2.35	31.1	0.32	71	38	24
93-2	619	SS Clay	1.7	6.1	8.4	5.5	35.6	29.4	29.5	3.35	30.7	0.76	15,400	50	25
92-9	740	SC Sand	—	2.9	8.0	36.4	17.2	22.0	24.4	—	38.5	0.28	240	44	24
92-8	743	CS Silt	5.1	7.5	9.7	4.2	7.4	43.6	44.8	2.30	25.5	0.32	421	26	18
87-9	878	SS Clay	2.2	6.3	10.7	9.3	23.7	29.6	37.4	4.25	59.2	0.48	2,020	34	22
84-2	899	SS Clay	2.7	7.8	9.9	17.6	10.1	24.3	48.0	3.10	63.7	0.35	7,490	28	14
85-3	1142	Silty Clay	4.9	9.4	—	—	4.5	28.2	37.3	—	64.3	0.21	9,520	26	21
76-6	1532	CS Silt	5.1	7.0	8.7	3.4	7.7	55.8	33.1	1.80	31.2	0.84	406	25	16
31	1537	Clayey Silt	5.8	7.8	10.2	0.5	5.1	55.2	39.7	2.20	35.8	0.27	1,058	24	20
25	1600	SS Clay	4.1	7.9	10.3	22.4	1.5	26.7	49.4	3.10	40.3	0.30	58	35	24
60-8	1663	CS Silt	4.3	6.1	8.5	6.7	12.8	60.8	19.7	2.10	30.8	0.40	215	26	19
53-7	1696	CS Silt	3.5	5.5	7.5	3.7	24.4	59.9	12.0	2.00	27.4	0.35	72	31	19
72-9	1703	CS Silt	4.5	6.9	9.1	2.3	15.1	57.3	25.3	2.30	24.7	1.06	381	42	28
60-9	1710	Silty Clay	7.2	9.6	10.6	0.4	12.2	22.0	68.2	1.70	23.3	0.72	5,430	27	19
46-2	1774	Clayey Silt	5.0	7.0	9.2	0.8	2.1	61.4	35.7	2.10	25.6	0.39	29	22	16
11	2000	SS Clay	4.4	7.7	10.4	0.6	21.8	30.1	47.5	3.00	28.9	0.31	2,400	22	16
9	2205	SS Clay	6.4	8.8	10.5	9.6	5.9	27.7	56.8	2.05	30.1	0.26	21,600	23	18
5	2386	Silty Clay	7.0	9.4	11.1	0.8	2.2	30.3	67.7	2.05	26.7	0.29	4,790	24	19
2	2760	SS Clay	5.0	8.2	10.3	1.0	16.4	29.2	53.4	2.65	23.6	0.34	27,400	17	14

a, foraminiferal number; b, number of species; c, number of genera.

Marine sedimentation

Arctic sediment is derived primarily from the marginal land masses surrounding the basin. Because of ice transport, much of the sediment originally could have been rafted onto the ice from almost any point on the periphery of the Arctic Ocean. Glacial ice plays an important part in the disintegration of rock materials. Once the rock becomes incorporated into the glacial ice it may be transported far out to sea before being dropped to the bottom. Streams or rivers deposit their loads on the surfaces of glaciers or land-fast pack-ice, whence the sediment is carried out to sea by the ice and deposited. Wind may also play a minor part in contributing sediment to the Arctic ice. Other methods by which ice may act as a transporting agent for sediment are bottom freezing and ice-shove against the shore. Nansen (1902) believed that sediment was transported across the entire basin by ice. "A minor contribution to the sediments of the Arctic is made by inflowing Gulf Stream water carrying various warm-water organisms" (Emery, 1949). As predicted by Emery, much of the sediment has been directly deposited by ice. How much is still uncertain, although research now

in progress on quartz-feldspar ratios as indicators of the degree of chemical weathering should help to solve the problem.

The terms "drift" (Antevs and MacClintock, *vide* Rice, 1952), for continental deposits, and "glacial marine sediments" (Hough, 1956; after Philippi, 1912), for sediments surrounding the Antarctic continent, have been proposed for sediments developed through ice transport. Sediment thus formed is generally very poorly sorted. According to Hough, a glacial marine sediment is "... composed mainly of material which has been transported from the land or shallow water by ice-rafting and has been dropped to the bottom when the ice melted." The lower size-limit of Hough's glacial marine sediment is 9 phi, or 0.004 mm., but the Arctic sediments are much finer, with colloidal material making up as much as 40 per cent of the sample.

Ice transport plays an important part in the distribution of shallow-water foraminifera in deep water. At least 5 per cent of each fauna shows the influence of shallow-water forms. This 5 per cent of the fauna

ARCTIC FORAMINIFERA

TABLE 2

NUMBER OF LIVING FORAMINIFERA IN EACH SAMPLE

Living Species	Station Number															
	99-12	96-7	104-7	80-10	80-8	81-7	93-2	92-9	92-8	87-9	84-2	85-3	76-6	31	25	60-8
<i>Nummoloculina</i> sp.	8	16			1		2									
<i>Cassidulina teretis</i>	1	3		1	3	1										
<i>C. norcrossi</i>	1															
<i>Ceratobulimina arctica</i>	2		foraminifera not preserved	1				1								
<i>Valvulineria arctica</i>	1			2		1										
<i>Parafissurina arctica</i>	2															
<i>Stetsonia horvathi</i>	1			5				1								
<i>Quinqueloculina</i> sp.	1															
<i>Eponides tener</i>	1			1												
<i>Triloculina trihedra</i>		2		1												
<i>Parafissurina curta</i>				1												
<i>Valvulineria horvathi</i>				1												
<i>Nonion affinis</i>				1												
<i>Bulimina aculeata</i>					1	1										
<i>Fissurina bassensis</i>					1											
<i>Lagena</i> sp. e					1											
<i>Spirillina vivipara</i>							1	1								
<i>Cassidulina icelandica</i>								1								
<i>Globigerina pachyderma</i>	3	11					4	14								

may contain as many as fifteen species. From research now in progress at Columbia University on carbon isotopes in Arctic cores, it may be possible to determine depositional rates.

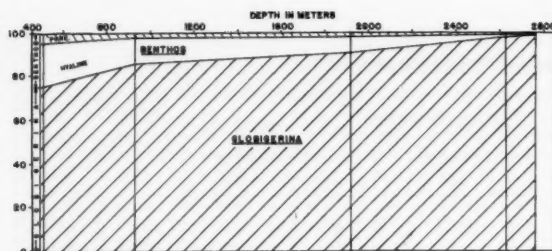
FORAMINIFERAL STUDIES

Previous work

More work has been done on foraminifera in the Arctic and Subarctic regions than is commonly recognized. The *Arctic Bibliography* (Anonymous, 1956) lists forty-four papers on foraminifera. Thirty papers cover Recent, and fourteen cover fossil zones. Almost as much work has been done on Arctic Recent foraminifera since World War II as had been done before; however, only three papers on Arctic fossil foraminifera have been written since the war. Of the thirteen post-war papers on Recent foraminifera of the Arctic, nine are Russian and four are American. The nine Russian papers are the work of a single woman, Z. G. Stschedrina. The early workers most worthy of note are Parker and Jones (1865), Carpenter (1878), Brady (1881*a*, 1881*b*, 1878, 1884), and Cushman (1933).

Papers including ecological information began with Brady, who, in 1881, published a paper on the for-

minifera and sediments of Novaya Zemlya. Gots (1894) gave distributional patterns for foraminifera of the Swedish Arctic Expedition in the vicinity of the Norwegian Sea and Spitsbergen. Kiaer (1899) described 166 species of foraminifera and discussed the clays in which they were found in the Norwegian and Greenland Seas. Nine years later (1908), he published a second paper, concerning foraminifera of Tromsø Sound, and several other invertebrate groups were included in the study. Kiaer's third paper, on the second Norwegian Arctic Expedition, appeared in 1909, and listed foraminifera and bottom sediments from the Barents, Kara, and Laptev Seas and the Arctic Basin north of the New Siberian Islands. Later, Spärrck (1933) described the submarine topography, bottom deposits, water temperature, and salinity in the Franz Josef Fjord complex, as well as invertebrate communities, including foraminifera, at depths below 200 meters. Phleger (1951, 1952) published two reports on zonation of foraminifera from the Canadian and Greenland Arctic. Stschedrina dealt with the taxonomy and depth distribution of more than 100 species in the Okhotsk Sea (1950*b*). Probably the most complete treatise on the ecology of Arctic Foraminifera is that of Stschedrina (1950*a*).



TEXT-FIGURE 6

GLOBIGERINA - HYALINE BENTHOS - PORCELLANEOUS
BENTHOS PERCENTAGES

On the basis of several collections and studies, she divided the fauna of the Arctic into the following ecological groups:

Upper sublittoral.....	0-80 meters
Sublittoral warm water	80-200 meters
Sublittoral cold water.....	80-200 meters
Deep sea.....	1000-3800 meters

These groups were compared with oceanographic conditions, and a summary comparison with the North Pacific and Atlantic faunas was made. Many of the samples of the present study come from the depth range omitted from the Russian work, i.e., 433-2760 meters.

Faunal aspect

General considerations: The Arctic fauna is composed of 50 genera with over 100 species. Six new forms are described. The most abundant foraminifera (averaging over 2 per cent) are found in the following groups: twelve species of the Rotaliidae, four species of the Buliminidae, three species each referred to the Cassidulinidae, Miliolidae, and Nonionidae, and two species of unilocular types. The unilocular species are highly diverse; however, they are statistically insignificant. Members of the fauna in general are unornamented except for two species of the genus *Bulimina* and several unilocular forms. On the average, 85 per cent of the normal benthonic fauna are hyaline, 14 per cent are porcellaneous, and less than one per cent are arenaceous (text-fig. 6). Arenaceous foraminifera are not present in most samples. This contrasts sharply with the foraminiferal fauna on the Russian side of the Arctic.

Living foraminifera: A total of nineteen species took at least some of the rose stain, and were thus considered living in this study. These foraminifera were not stained as deep a rose as foraminifera taken off the Pacific coast. This casts serious doubt on the validity of the results obtained with the staining

process as used on Arctic foraminifera; however, the results indicate that living conditions are better in the shallower depths. This is a reasonable assumption, inasmuch as stained foraminifera were found in all seven of the shallowest samples that were preserved in alcohol, but in only three of the twelve deepest-water samples.

The most abundant stained species (not considering *Globigerina*) was *Nummuloculina* sp. (Table 2). In all the samples, a total of twenty-eight specimens of *Nummuloculina* stained. Twenty-four of the twenty-eight individuals were in the two shallowest samples (Table 2).

Station 96-7 (445 meters) showed the largest number of stained individuals, with a total of thirty-two individuals stained; sixteen were *Nummuloculina* sp. and three were *Cassidulina teretis*. Disregarding *Globigerina*, *Cassidulina teretis* is statistically the most important species in the thanatocoenosis at this depth.

Globigerina: In the shallower stations (400-500 meters), specimens of *Globigerina* comprise an average of 75 per cent of the fauna; as the depth of water increases, the percentages of *Globigerina* increase until, in the deeper stations, (2000-2760 meters) they average 98 per cent of the fauna. The specimens of *Globigerina* are here regarded as *Globigerina pachyderma* (Ehrenberg). This species is quite variable, being generally rather small (0.062-0.250 mm.), with a thick quadrate test; the aperture is at the base of the last septal face, extending to the umbilicus and periphery, with or without a lip. Morphological variations are obvious. However, in attempting to separate distinctive types for counting purposes, the author was unable to obtain valid reproducible counts on the same group of 300 individuals. Sinistral coiling predominated in the specimens of *Globigerina* (98 per cent). There were no significant changes in the coiling direction with depth.

Relationship to Atlantic and Pacific faunas: Many forms known from both the Atlantic and the Pacific are found in the Arctic waters; however, those from the Atlantic are cosmopolitan, whereas some of the Pacific forms have not been reported outside the Pacific area. Examples of Japanese foraminifera in the Arctic are *Cruciloculina japonica* Asano and *Epistominella naraensis* (Kuwano). Thirty species were specifically identical or very closely related to the Timms Point species described by Cushman and Gray (1946).

Ornamentation: The ornamented species *Bulimina aculeata* d'Orbigny, seems to become more spinous, and the spines become longer, with depth. No patterns of ornamentation change were noted in the unilocular forms.

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TABLE 4
FORAMINIFERAL LIST AND PERCENTAGE OCCURRENCE IN EACH SAMPLE EXCLUSIVE OF GLOBIGERINA

STATION NUMBER	99-12	96-7	104-7 TOP	(72 1/2-75)	(62 1/2-65)	(52 1/2-55)	(42 1/2-45)	(32 1/2-35)	(22 1/2-25)	(12 1/2-15)	(2 1/2-5)	(0-2 1/2)	80-10	80-8	81-7	93-2	92-9	92-8	87-9 TOP	(80-82 1/2)	(70-72 1/2)	(60-62 1/2)	(50-52 1/2)	(40-42 1/2)	(30-32 1/2)	(20-22 1/2)	(10-12 1/2)	(0-2 1/2)	84-2	83-3	76-6	31	25	60-8	53-7	72-9	60-9 TOP	(12 1/2-15)	(2 1/2-5)	46-2	11	9	5	2			
DEPTH IN METERS	433	445	497										500		510	619	740		878										899	1142	1532	1537	1600	1663	1696	1703	1710										
NORTH LATITUDE	82° 32'	82° 38'	82° 45'										82° 45'		82° 49'	82° 50'	82° 40'		82° 54'										82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
WEST LONGITUDE	95° 40'	93° 15'	94° 10'										93° 10'		93° 20'	93° 05'	93° 00'		92° 45'										93° 05'	92° 45'	92° 35'	81° 30'	81° 20'	89° 20'	90° 15'	90° 20'	89° 20'										
1 <i>Cassidulina teretis</i>	23 40	36 45	44 39	39 42	43 46	27 37	54 45	18 12	4 12	38 35	37 35	31 32	41 30	22 16	4 2	2 14	10 54	4 6	19 1	89° 30'	90° 30'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
2 <i>Nummuloculina</i> sp.	18 23	11 11	16 15	10 17	17 19	11 4	3 7	3 5	4 2	21 9	7 6	1 3	2 2	1 4	2 2	2 6	2 3	2 2	2 1	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
3 <i>Epistominella nanaensis</i>	7	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
4 <i>Ceratulimina arctica</i>	3	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
5 <i>Cibicides lobatulus</i>	3	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
6 <i>Elphidium bartletti</i>	3	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
7 <i>Cassidulina telandica</i>	13	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
8 <i>Valvulinella arctica</i>	13	6	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	90° 15'	90° 20'	91° 10'	85° 58'	2000	1774				82° 50'	82° 50'	83° 00'	84° 40'	84° 39'	83° 11'	83° 15'	83° 07'	83° 11'										
9 <i>Trochammina nana</i>	×	1	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×		
10 <i>Mitrolinella circularis</i>	2	3	1	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	
11 <i>Cibicides</i> cf. <i>C. conoides</i>	5	2	3	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
12 <i>Cassidulina norcrossi</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
13 <i>Valvulinella horvathi</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
14 <i>Pyrgo elongata</i>	4	6	3	2	1	1	2	1	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	
15 <i>Triloculina trihedra</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
16 <i>Epistominella arctica</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
17 <i>Eponides tener</i>	4	5	3	8	4	8	5	3	4	6	10	9	3	10	13	10	2	4	3	6	4	7	5	17	20	14	24	45	22	14	29	10	8	25	5	6	12	17	20	27	50	16	16	16	16	16	
18 <i>Quinqueloculina akneriana</i>	4	5	3	8	4	8	5	3	4	6	10	9	3	10	13	10	2	4	3	6	4	7	5	17	20	14	24	45	22	14	29	10	8	25	5	6	12	17	20	27	50	16	16	16	16	16	
19 <i>Sietsonia horvathi</i>	4	5	3	8	4	8	5	3	4	6	10	9	3	10	13	10	2	4	3	6	4	7	5	17	20	14	24	45	22	14	29	10	8	25	5	6	12	17	20	27	50	16	16	16	16	16	
20 <i>Cibicides vuellerstorfi</i>	10	5	5	5	3	4	3	5	1	6	9	2	3	7	12	27	13	13	9	11	7	4	8	20	22	15	10	4	11	6	8	29	10	19	10	25	8	4	9	4	2	2	2	2	2		
21 <i>Buliminella elegantissima</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
22 <i>Patellina corrugata</i>	1	1	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
23 <i>Perforissurina arctica</i>	1	1	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
24 <i>Robertina</i> (<i>Robertinoides</i>) <i>charlottensis</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
25 <i>Virgulina nodosa</i>	2	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
26 <i>Cassidulina quadrata</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
27 <i>Perforissurina sublata</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
28 <i>Quinqueloculina</i> sp.	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
29 <i>Perforissurina curta</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
30 <i>Rotorbinella vertiformis</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
31 <i>Lagena aloeki</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
32 <i>Cruciloculina japonica</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
33 <i>Rophex</i> sp.	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
34 <i>Pateoris hauerioides</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
35 <i>Oolina melo</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
36 <i>Lagena hexagona</i>	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

[illegible]

[illegible]

PERCENTAGE OF GLOBIGERINA/TOTAL SAMPLE

[illegible]

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TABLE 3

FAUNAL GROUPS AND INDICATOR SPECIES WITH PERCENTAGE OF OCCURRENCE

Temperature in °C.	(+.03)-(+.05)	(+.03)-(-.02)	(-.39)-(-.42)	(-.39)-(-.40)
Depth in meters	433-510	619-1142	1532-2000	2250-2760
Indicator species	Shelf	Slope	Apron	Abyssal
1. <i>Cassidulina teretis</i> *	36	14	3	
2. <i>C. icelandia</i>	2	1	x	x
3. <i>Nummuloculina</i> sp.	6	3	2	x
4. <i>Ceratobulimina arctica</i> n. sp.	3	3	2	2
5. <i>Cibicides lobatus</i>	3	2	x	
6. <i>Elphidium bartletti</i>	3	2	1	
7. <i>Epistominella naraensis</i>	4	x	x	x
1. <i>Valvulineria arctica</i> n. sp.*	5	8	2	3
2. <i>Trochammina nana</i>	x	2	x	
3. <i>Miliolinella circularis</i>	2	2	2	x
4. <i>Cibicides</i> sp. cf. <i>C. conoides</i>	2	3	1	x
5. <i>Cassidulina norcrossi</i>	2	3	x	
1. <i>Eponides tumidulus</i> var. <i>horvathi</i> n. var.*	1	9	19	5
2. <i>Pyrgo elongata</i>	x	x	1	x
3. <i>Triloculina trihedra</i>	3	3	4	2
4. <i>Epistominella arctica</i> n. sp.	1	1	5	
1. <i>Eponides tener</i> *	7	10	21	29
2. <i>Quinqueloculina akneriana</i>	2	2	6	12
3. <i>Stetsonia horvathi</i> n. sp.	5	11	14	14
4. <i>Cibicides wuellerstorfi</i>	x	1	3	6

* The starred species are those found living in the Arctic sample.

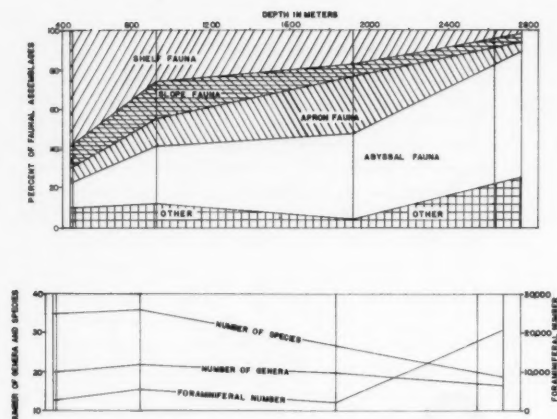
Abnormalities: Several abnormalities were observed, such as uncoiling in *Cibicides lobatus* d'Orbigny, squashed or double-chambered unilocular forms, irregular chamber addition in the Miliolidae, and twinning or intergrowths in rotaloid forms. Irregular growth was noted in many rotaloid and planispiral species. Not more than one per cent of the fauna at any one station appeared to the author to be abnormal; this, however, is a subjective matter depending upon the limits placed on each species. *Cibicides lobatus* is notoriously irregular, and it would be possible for a worker to place such narrow limits on this species that only 50 per cent would be considered normal. It appears from first observations of the hostile physical environment that there would be many abnormal forms in comparison with other areas. This, however, is a difficult comparison to make because there are only two papers on abnormalities in the foraminifera (Le Calvez, 1951; and Arnal, 1956).

Associated animals: Copepods are the most abundant group of animals in the upper layers of water. Unfortunately, little work has been done on this group of animals in the Ice-Island collections. Second in importance are the amphipods. Dr. J. L.

Barnard, of the University of Southern California, has made available a large amount of unpublished information on these forms.

The amphipod species *Pseudoalibrotus nanseni* Sars and *Gammarus wilkitzkii* Birula are the two most abundant of seven known and one new amphipod species. In a dissection of two dozen Arctic amphipod digestive tracts, no recognizable organic remains were found. Foraminifera and diatoms have been found in the stomachs of some amphipods in other areas. Brady (1881) reported that many Arctic forms of *Globigerina* are benthonic. This may account for the lack of foraminiferal tests in the amphipods' digestive tracts. Brady based his conclusion on the fact that the thick-walled *Globigerina* were not taken in plankton tows but were numerous in the bottom deposits. Brady's contention that the Arctic *Globigerina* are benthonic is supported by the stain results of this study. More individuals of the genus *Globigerina* became stained than any other species.

Other planktonic animal groups present are polychaetes, of which four species were found (Knox,



TEXT-FIGURE 7

BATHYMETRIC DISTRIBUTION OF FAUNAL ASSEMBLAGES

unpublished manuscript), ostracodes, isopods, radiolarians, nemerteans, and Larvacea. The benthonic groups include gastropods, pelecypods, bryozoans, sponges, sipunculids, and one unidentified coral. This high Arctic fauna is relatively sparse with regard to species and numbers, as compared with the good crustacean and molluscan faunas of northern Alaska (Mohr, personal communication).

Little is known of the volume of phytoplankton in the Arctic Ocean. The highest phytoplankton populations occur during August, according to Shirshov (1944). This is of importance in determining zooplankton food supplies. The zooplankton are in turn important to the food supply of bottom scavengers such as the protozoa.

Barnard indicates that the life span of Arctic amphipods may be from six to ten years, as compared with approximately one year for the amphipods off the coast of southern California. This is based on the reproductive cycle of the amphipods, which lay their eggs in December, hatch in May, and leave the brood pouch in August. Normally this process is much accelerated, and there may be as many as six reproductive cycles in a year's time. Since the amphipod life span is prolonged by a cold environment, similar relationships might also be demonstrated in the associated groups of organisms, including the protozoa.

Faunal zones of foraminifera

Zonation: Zonation of this rather uniform physical environment was carried out when it became apparent, during counting of the fauna, that a break or distinct change in faunal content occurred

at a depth of approximately 1000 meters. To show this faunal change, it was necessary to group the stations into four depth groups coinciding with the physiography (Table 2) and temperature (see text-fig. 2). The fauna is then conveniently divisible into the following four zones (see text-fig. 7):

ZONE	DEPTH IN METERS	DOMINANT SPECIES
Shelf	433-510	<i>Cassidulina teretis</i>
Slope	619-1142	<i>Valvulineria arctica</i>
Apron	1532-2000	<i>Eponides tumidulus</i>
Abyssal	2250-2760	<i>Eponides tener horvathi</i>

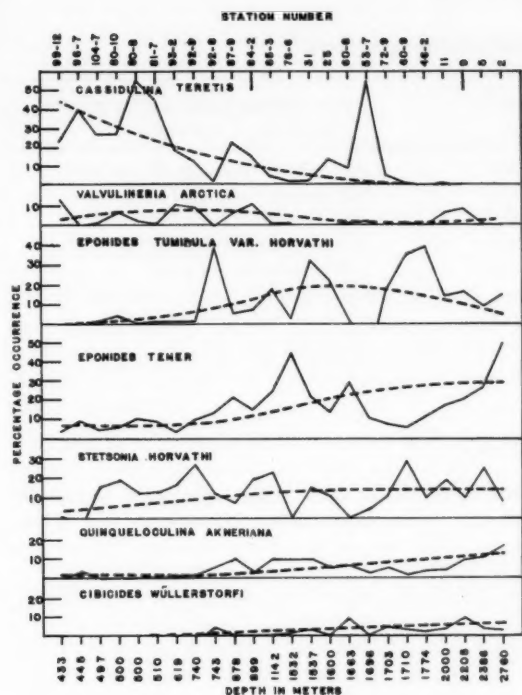
With the exception of *Cassidulina teretis* and *Cibicides wuellerstorfi*, the species present occur at all depths sampled. This does not necessarily indicate that the foraminifera are unzoned. In each case in which a species has been assigned to a faunal zone, the species listed is most abundant in the zone indicated (Table 3).

Shelf fauna: The shelf zone (433-510 meters; $+0.30$, $+0.03$, and $+0.50^{\circ}\text{C}$.; 34.80-34.90 parts per thousand salinity) contains seven species of foraminifera (Table 3). The highest percentages of the genus *Cassidulina* are reported on the outer part of the shelf on the east coast (Parker, 1948) and on the west coast (Natland, 1933, and Bandy, 1953) of the United States. Thus it appears that the faunal aspect is shelf-like. The total fauna of the shelf zone is composed of 45 per cent shelf species, with the slope, apron, and abyssal faunas present in rather high percentages. Typically, when cold, deep-water faunas are found mixed with an abundance of warm, shallow-water faunas, the former are reworked (Hedberg, 1934, and Crouch, 1954). This is not the case here.

Slope fauna: The slope fauna (619-1142 meters; $+0.03$ and -0.2°C .; 34.84-34.94 parts per thousand salinity) is characterized by five species. These are the species that occur most abundantly on the slope (Table 3). *Valvulineria arctica* n. sp. is the only foraminifera abundant enough to be an indicator species; the remaining species of the slope fauna are commonly associated with *Valvulineria arctica* but are not necessarily indicative of slope conditions.

Apron fauna: The apron fauna (1532-2000 meters; -0.02 and -0.42°C .; 34.90-34.97 parts per thousand salinity) is characterized by *Eponides tumidulus* var. *horvathi* n. var., which is found associated with *Pyrgo elongata* (d'Orbigny), *Triloculina trihedra* Loeblich and Tappan, and *Epistominella arctica* n. sp. *Triloculina trihedra* is found in

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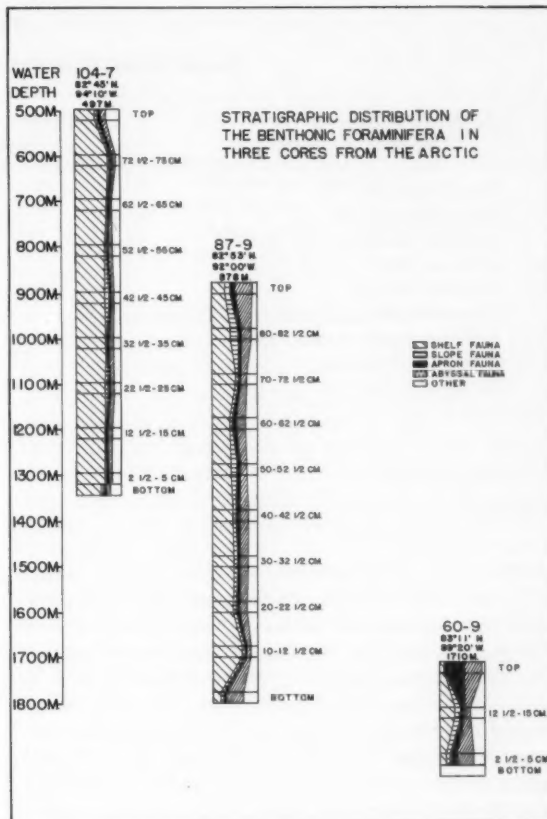


TEXT-FIGURE 8

PERCENTAGE DISTRIBUTION OF IMPORTANT INDICATOR SPECIES VS. DEPTH

water as shallow as 21.6 meters (Loeblich and Tappan, 1953) and shows little percentage variation, indicating that it is probably eurybathic; however, Loeblich and Tappan give no abundance data, so that the matter is left open. *Pyrgo elongata* may be eurybathic, on the same evidence; in this survey, both species were found most abundantly with *Eponides tumidulus* var. *horvathi*.

Abyssal fauna: The abyssal fauna (2250–2760 meters; -0.40 and -0.42° C.; salinity unknown, probably 35.00 parts per thousand) is composed of four good indicator species; they are *Eponides tener* Brady, *Quinqueloculina akneriana* d'Orbigny, *Stetsonia horvathi* n. sp., and *Cibicides wuellerstorfi* (Schwager). Curtis (1955) pointed out that *Quinqueloculina* is typically found in shallow water but is not excluded from a deeper habitat. In this study the percentages of *Quinqueloculina* increase with depth from a few per cent in the shallower stations up to 15 per cent in the deeper stations. Lowman (1949) reported that the Miliolidae range into various types of environments, but that they prefer a less populated area if possible. *Cibicides wuellerstorfi* is a deep, cold-water



TEXT-FIGURE 9

STRATIGRAPHIC DISTRIBUTION OF BENTHONIC FORAMINIFERA IN THREE CORES FROM THE ARCTIC

species of both the Atlantic and Pacific Oceans, and is thus found in its normal habitat in the Arctic.

Discussion: Qualitatively the fauna is uniform, i.e., the same species are found in the shallowest and deepest stations, with the exception of *Cassidulina teretis* Tappan and *Cibicides wuellerstorfi*. A striking quantitative difference occurs, however, between the upper and lower limits of the study.

Seven species are abundant enough statistically to be used individually as indicator organisms. They include the two restricted species *Cassidulina teretis* and *Cibicides wuellerstorfi*, as well as the unrestricted species *Valvulineria arctica*, *Eponides tumidulus* var. *horvathi*, *Eponides tener*, *Stetsonia horvathi*, and *Quinqueloculina akneriana*. The percentage abundance at each station shows that each species varies considerably; however, definite trends are established from shallow to deep water (see text-fig. 8).

GREEN

TABLE 5

WATER DEPTH EVALUATION WITH FORAMINIFERAL DATA

Indicator species or type of information	Value and source of information	Approximate depth indicated and method of determination
<i>Cassidulina teretis</i>	19% (Table 4)	700 meters (text-fig. 8)
<i>Valvulineria arctica</i>	6% (Table 4)	500 meters (text-fig. 8)
<i>Eponides tumidulus</i> var. <i>horvathi</i>	3% (Table 4)	500 meters (text-fig. 8)
<i>Eponides tener</i>	5% (Table 4)	500 meters (text-fig. 8)
<i>Stetsonia horvathi</i>	8% (Table 4)	510 meters (text-fig. 8)
<i>Quinqueloculina akneriana</i>	not present	less than 600 meters (text-fig. 8)
<i>Cibicides wuellerstorfi</i>	not present	less than 600 meters (text-fig. 8)
Number of species	30 (Table 1)	1600 meters (text-fig. 7)
Number of genera	21 (Table 1)	700 or 1100 meters (text-fig. 7)

APPLICATION OF DATA

Core 104-7

From text-figure 9 it can be seen that conditions of sedimentation are uniform over considerable lengths of core 104-7 (from 72½-75 cm. to 2½-5 cm.). This core appears to have deepened within the top 10 cm., as indicated by the reduced percentages of the shelf fauna. However, before deepening can be inferred, reduced percentages of the shelf fauna would have to appear in several cores from the same area. From text-figure 8 it is seen that the indicator species are rather patchy in their geographic distributional patterns. The low percentage of shelf fauna in the surface layers of core 104-7 is the result of the patchy distribution of *Nummuloculina* sp., *Ceratobulimina arctica*, and *Cibicides lobatus* (Table 4).

Core 87-9

The same uniform conditions exist in core 87-9 except for the lower section of the core. At 10-12½ cm. from the bottom of the core, an increase in the shelf fauna is seen, and at the extreme bottom of the core, there is a marked decrease in the shelf fauna with an increase in the abyssal fauna. Reworking is a possible interpretation for the high percentage of shelf fauna at 10-12½ cm.

Faunal conditions at 0-2½ cm. in core 87-9 are similar to the conditions found in the abyssal zone, as shown in text-figure 7. Isostatic adjustment of the crust during the building of the Lomonosov Range is a possible, although not probable, interpretation. Neither sample is sufficiently different from the typical picture displayed throughout the length of the core to permit a definite conclusion. Both changes may be due to patchy distributional patterns.

Core 60-9

Core 60-9 shows a striking contrast in the center interval, with significant changes in all faunal groups and sediment characteristics. Because of these radical changes, an interpretation will be attempted. The surface assemblage is characteristic of an apron fauna when compared with text-figure 7 (as it should be, with 1710 meters of water). At 10 cm. below the surface (12½-15 cm. from the bottom of the core), the shelf fauna increases to 32 per cent. Noting that the shelf fauna comprises 32 per cent of the total assemblage at approximately 825 meters, one could assume from text-figure 7 that this is a displaced fauna from the slope zone. This, however, is not the extent of the interpretive data available. The slope fauna (13 per cent) indicates a depth of 600 meters or 1400 meters (text-fig. 7). It is necessary to decide which is the more reasonable answer when all the evidence is in. The apron fauna (8 per cent) indicates a depth of approximately 500 meters, not 2650 meters, since *Cassidulina teretis* is present (19 per cent, Table 4). The abyssal fauna indicates a depth of 500 meters.

Next, by using indicator species rather than faunal groups, a new set of depth data can be obtained. These, with interpretations based on the number of species and number of genera, are given in Table 5. The absence of the abyssal indicators *Quinqueloculina akneriana* and *Cibicides wuellerstorfi* is significant in supporting the idea of a displaced shoal fauna.

Throughout the limits of the study, the hyaline-porcellaneous ratios remained at a constant value of 15 per cent, plus or minus an average of 7 per cent. Hyaline-porcellaneous ratios are not indicative of depth. Coiling ratios were uniform throughout the depths sampled, and are thus useless in interpreting depth relationships. It is interesting to note that 2

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TABLE 6

WATER DEPTH EVALUATION WITH SEDIMENT DATA

Type of information used	Value and source of information	Approximate depth indicated and method of determination
Median diameter	7.5 Φ (Table 1)	400 meters (text-fig. 5)
Sorting coefficient	2.25 Φ (Table 1)	2000 meters (text-fig. 5)
Sediment greater than —2 Φ	0 grams (Table 1)	2800 meters plus (text-fig. 5)
Foraminiferal number	52 (Table 1)	not usable (text-fig. 7)

per cent of spinose *Bulimina* species were present; the spines were sparse and rather short. The relatively low *Globigerina* percentage (62 per cent) indicates a very shallow origin for the sample, less than 433 meters.

The results tend to indicate a rather shallow origin for the faunal assemblage found in this section of the core. However, more data must be gathered before the interpretive work can begin.

The sediments, as well as the foraminifera, show significant trends and diagnostic characteristics. From an examination of these trends, greater depths are indicated, as shown in Table 6. The organic matter and soluble material change with depth of burial and are thus not considered valuable in connection with a problem of this kind.

We are now ready to examine the data to see what interpretations can be made and conclusions reached concerning the anomalous conditions that exist at 10 cm. below the surface of core 60-9. The faunal groups and the indicator species suggest a rather shallow origin for the foraminifera in the sample. The number of species is characteristic of a deep-water fauna (1600 meters). The number of genera indicates a shallow origin for the site of original

deposition. The sediment data range from non-indicative to typical of depths greater than 2800 meters. Some of the depth indications given are certainly invalid and must be discarded, since the sample cannot have originated simultaneously in both shallow and deep water.

Let us now see which, if any, data can be discarded. The number of species indicates a depth of 1600 meters, but the species counts vary from seventeen to fifty, and only an insignificant trend was established. This determination can therefore be viewed with skepticism. The number of genera presents a somewhat more reliable picture, since many of the rare species were included in the four unilocular genera *Lagena*, *Oolina*, *Fissurina*, and *Parafissurina*. The depth determination based on the number of genera will therefore be considered to be the more valid. As

many as twenty-one genera occur between 700 and 1100 meters. Since all other foraminiferal data indicate a shallow origin, the shallower value (700 meters) for the number of genera is indicated. At this point it is possible to discard the 1400-meter determination indicated by the shelf fauna and to retain the 600-meter determination. By averaging the results of the foraminiferal bathymetric determinations, a depth of less than 600 meters is obtained.

Sediment data in general do not harmonize with the depth indications given by the foraminifera. This does not mean that the data are wrong, indecisive, or that erroneous interpretations have been made; it does mean that a logical explanation must now be made to account for the difference. If the sediment data coincided with the foraminiferal data, the problem could be solved by simply stating that the sediments and foraminifera must certainly have been deposited in water shallower than that in which they now rest and that subsequent vertical movement of the bottom of the Arctic Ocean has taken place. If vertical movement of the magnitude indicated (700 meters) had taken place, a number of samples would have been displaced, including those of cores 104-7 and 87-9.

The sediment data are now used to support the contention that displacement has taken place. The particulate material greater than —2 ϕ was not carried to the bottom of the slide. The sorting coefficient and median diameter now become characteristic of turbidity flows rather than depth.

The foraminifera support the conclusion that this is the result of a turbidity flow, since a number of specimens stained with the rose bengal, indicating that they were buried rapidly and had not had time to decay. Bacterial action is probably slow on the surface of the sediment in water below 0° C., and normally decreases with depth of burial.

The author concludes from the foraminiferal assemblages and indicator species that the foraminifera lived in water less than 600 meters deep. The sediment data indicate that turbidity-flow action

has taken place, displacing the foraminifera by carrying them downslope into 1710 meters of water. The flow has subsequently been covered over by a few centimeters of Recent sediment in 1710 meters of water.

SUMMARY

The continental shelf in the vicinity of Ellesmere Island is 500 meters deep and 80 to 130 kilometers wide. The sediments are typically ice-rafted, generally fine-grained and poorly sorted; they have an average of 40 per cent soluble material, are low in organic carbon, and from a megascopic examination of the coarse fraction appear to resemble the rock and mineral material found on Ice-Island T-3 (Stoiber, Lyons, Elberty and McCrehan, 1956). The deep-water sediments carry a significant percentage of ice-rafted, very shallow-water foraminifera and sediment (0-20 meters).

In general, the Arctic fauna is sparse and not as diversified as that of lower latitudes; however, this generalization cannot be applied to all animal groups or to all parts of the Arctic. The foraminiferal fauna is primarily hyaline, with a very large percentage of *Globigerina*. Porcellaneous foraminifera comprise an average of 2 per cent of the total fauna. Qualitatively the fauna is uniform, but quantitatively there is a striking difference between the upper and lower limits of the study.

The foraminifera are divisible into four zones, based upon quantitative methods of analysis. The major faunal break coincides with the 0° C. isotherm; the minor breaks correspond to changes in slope of the bottom profile. Only two important species (*Cassidulina teretis* and *Cibicides wuellerstorfi*) are restricted in depth.

The faunal assemblage at station 53-7 is the result of the displacement of a bathymetrically shallower fauna. Evidence concerning the foraminifera and sediments in the middle section of core 60-9 leads to the conclusion that turbidity-flow action has taken place.

The most reliable and consistent ecological indicators found in this study were: 1) *Globigerina* total fauna ratios; 2) percentage of indicator species; 3) faunal groups; and 4) percentage of sediment greater than -2 phi (ice-rafted material). The author believes that paleoecological interpretations can be made on the basis of Recent Arctic ecology in areas of deep-water sedimentation during intense Plio-Pleistocene glaciation.

SYSTEMATIC DESCRIPTIONS

In the following section, five new species and one new variety are described. Numerous foraminiferal species that seem to have no counterpart in the literature were encountered as traces in this study, but in keeping with the objectives of this paper, i.e., foraminiferal ecology, it was thought best to leave detailed descriptions and figures of these species to a taxonomic work. Therefore, the unidentified species that are statistically unimportant (averaging less than 2 per cent of the benthonic fauna) are given in the annotated list without specific name, followed by a short description.

The new species, although never before reported, may have wide geographic distribution. If a 250-mesh screen (0.062 mm. opening) is used in the washing process, these small foraminifera are retained on the screen; the use of larger screens may account for their absence in other studies.

All holotypes and paratypes have been deposited in the paleontological collection of the University of Southern California, Los Angeles.

Order FORAMINIFERA

Family NODOSARIIDAE Schultz, 1854

Genus PARAFISSURINA Parr, 1947

Parafissurina arctica Green, new species

Plate 1, figure 2a-b

Test rounded in side view, slightly compressed; periphery with a large, sharp keel; keel variously ornamented with spines, teeth, and plates, the length of the ornamentation varying greatly; wall finely perforate; aperture hooded, with an entosolenian tube of variable length, ranging from three-fourths the length of the test to extending to the bottom of the test and halfway up the opposite face of the test; the tube is attached to the dorsal wall of the test and continues as a tunnel to the flared opening into the chamber.

Diameter of the holotype 0.30 mm.; width 0.15 mm.

Remarks: Parr (1950) described several species of *Parafissurina* from the Antarctic; however, none had ornamentation on the keel. A few individuals of this species occurred in almost every sample. The greatest abundance of *P. arctica* occurred at station 87-9, where it made up 4 per cent of the benthonic fauna. Typically, the toothed individuals had the shorter entosolenian tube, whereas the individuals with a plate on the keel had longer tubes; however, intergradational forms were found.

Types and occurrence: Holotype, U.S.C. no. 4625; paratypes, U.S.C. no. 4626. Type locality: Arctic Ocean, Ice-Island biological station no. 87-9, lat. 82°54' N., long. 92°45' W.; depth 878 meters. Age: Recent.

ARCTIC FORAMINIFERA

Family BULIMINIDAE Jones, 1876
Genus CERATOBULIMINA Toulou, 1915

***Ceratobulimina arctica* Green, new species**
Plate 1, figure 1a-c

Test elongate oval in side view; edge rounded; periphery slightly lobate; chambers inflated, few for the genus, four to six chambers in a single whorl, glassy to opaque; the large, round initial chamber followed by three to five rapidly elongating chambers exhibiting a slight twist; sutures depressed and slightly curved; aperture opening into a vestibule formed by a dorsal extension of the chamber wall, the vestibule opening into a roughened ventral umbilicus; the angular junction of the dorsal extension of the last chamber with the last chamber form a suture up and across the peripheral face of the test.

Length of the holotype 0.25 mm.; greatest breadth 0.08 mm.; greatest thickness 0.06 mm. Length of the paratypes 0.27-0.20 mm.; breadth 0.18-0.06 mm.; thickness 0.10-0.04 mm.

Remarks: This species is most abundant in the shallowest stations of this survey (433-510 meters). It is well represented, making up 7 per cent of the benthonic species at the shallowest station (433 meters). It is quite distinctive and not easily confused with any other species in the fauna. The test and chamber shape most closely resemble *Cerobertina bartrami*, but this species does not have the cerobertine supplementary chambers along the umbilical margin.

Types and occurrence: Holotype, U.S.C. no. 4635; Paratypes, U.S.C. no. 4636. Type locality: Arctic Ocean, Ice-Island biological station no. 96-7, lat. 82°38' N., long. 93°15' W.; depth 445 meters. Age: Recent.

Family ROTALIIDAE Reuss, 1860
Genus VALVULINERIA Cushman, 1926

***Valvulineria arctica* Green, new species**
Plate 1, figure 3a-c

Test rotaloid, oval in side view, relatively flat for the genus, edge broadly rounded; periphery lobate; chambers not inflated in the early portion, only slightly inflated in the later portion of the test; eight or nine chambers in the final whorl, one and one-half whorls visible on the dorsal side of the test; sutures slightly, depressed in the last few chambers; umbilicus on the ventral side open, with or without papillae; aperture beneath a valvular flap, the flap very thin and transparent, extending over the umbilicus.

Diameter of the holotype 0.13 mm.; width holotype 0.05 mm. Diameter of the paratypes 0.13-0.11 mm.; width 0.06-0.04 mm.

Remarks: This species is similar to *Valvulineria ochotia* Stschedrina; however, it differs in being flatter and smaller. *Valvulineria arctica* occurs most abundantly at

the shallowest station of the survey (433 meters), but it averages 8 per cent of the benthonic fauna in the depth interval between 619 and 1142 meters.

Types and occurrence: Holotype, U.S.C. no. 4629; paratypes, U.S.C. no. 4630. Type locality: Arctic Ocean, Ice-Island T-3 biological station no. 99-12, lat. 82°32' N., long 95°40' W.; depth 433 meters. Age: Recent.

Genus EPONIDES Montfort, 1808

***Eponides tumidulus* (Brady) var. *horvathi* Green, new variety**
Plate 1, figure 5a-c

Test rotaloid, round in side view, planoconvex with a high dorsal spire; color brown to orange-brown; edge broadly rounded; periphery lobate; chambers inflated, six to eight visible on the ventral side, three and one-half whorls visible dorsally; sutures ventrally radial and depressed, dorsally radial in the early portion of the test, tending to become tangential in the later portion of the test; wall finely perforate; umbilicus on the ventral side, open; aperture open widest on the periphery, but extending into the umbilicus.

Diameter of the holotype 0.12 mm.; width 0.10 mm. Diameter of the paratypes 0.10-0.14 mm.; width 0.08-0.12 mm.

Remarks: This species is the most abundant member of the apron fauna, averaging 19 per cent of the benthonic fauna at depths between 1532 and 2000 meters. The bright polished surface of this small foraminifera, along with its distinctive color, makes it readily recognizable. It is very similar to the typical form of the species, but differs in the lack of secondary growth on the dorsal side, and in the open umbilicus, lesser inflation, greater number of whorls visible dorsally, and greater number of chambers visible ventrally.

This species is named in honor of Mr. Charles Horvath, who collected the samples in conjunction with the United States Air Force high Arctic research program on Ice-Island T-3.

Types and occurrence: Holotype, U.S.C. no. 4631; paratypes, U.S.C. no. 4632. Type locality: Arctic Ocean, Ice-Island biological station no. 92-8, lat. 82°40' N., long. 93°00' W.; depth 740 meters. Age: Recent.

Genus EPISTOMINELLA Husezima and Maruhasi, 1944

***Epistominella arctica* Green, new species**
Plate 1, figure 4a-b

Test minute, rotaloid, biconvex, last chamber greatly inflated, test opaque, small; edge broadly rounded; periphery lobate; all chambers slightly inflated, four or five chambers in the last whorl, two whorls visible on the dorsal side; sutures slightly depressed; wall

finely perforate; aperture elongate, in the plane of coiling, the entrance recurved owing to an overgrowth of the dorsal wall at times pinching off the aperture before it reaches the base of the chamber, leaving the aperture elevated in the face; however, the suture always extends to the base of the last chamber.

Diameter of the holotype 0.07 mm.; width 0.03 mm.

Remarks: This species is very small and is distinguished by the large size of the final chamber. *Epistominella arctica* occurs most abundantly (averaging 5 per cent) in the depth interval between 1532 and 2000 meters.

Types and occurrence: Holotype, U.S.C. no. 4627; paratypes, U.S.C. no. 4628. Type locality: Arctic Ocean, Ice-Island biological station no. 11, lat. 85°58' N., long 91°10' W.; depth 2000 meters. Age: Recent.

Genus STETSONIA Parker, 1954

Stetsonia horvathi Green, new species

Plate 1, figure 6a-b

Test small, usually quadrate in side view, generally glassy but may be opaque, planispiral involute, with four or five chambers in the last whorl; test flat, edge subrounded, periphery smooth; sutures slightly depressed, slightly curved; aperture a high arched opening at the base of the last septal face, somewhat curved, situated in a depression. In the glassy specimens the previous whorls are clearly visible through the outer wall, causing the sutures to appear to widen toward the umbilicus.

Diameter of the holotype 0.10 mm.; width 0.04 mm. Diameter of the paratypes 0.07-0.10 mm.; width 0.03-0.04 mm.

Remarks: This species, although planispiral, at times shows a tendency to be rotaloid, indicating its epistominelloid ancestry, as suggested by Parker (1954). *Stetsonia horvathi* is more involute than is indicated in the type species, but the high arched aperture indicates a distinct relationship to *Stetsonia*. *Stetsonia horvathi* occurs most abundantly in the deeper-water stations, averaging 14 per cent in depths between 2250 and 2760 meters.

This species is named in honor of Mr. Charles Horvath, who collected the samples in conjunction with the United States Air Force high Arctic research program on Ice-Island T-3.

Types and occurrence: Holotype, U.S.C. no. 4633; paratypes, U.S.C. no. 4634. Type locality: Arctic Ocean, Ice-Island biological station no. 11, lat. 85°58' N., long. 91°10' W.; depth 2000 meters. Age: Recent.

ANNOTATED LIST OF SPECIES

The original references to the species found in this survey are listed below. The starred species are those found living in the Arctic samples. The numbers in parentheses following the reference are the numbers of the species in Table 4.

Angulogerina occidentalis (Cushman) = *Uvigerina occidentalis* Cushman, 1923, U. S. Nat. Mus., Bull. 104, p. 169. (97)

Astacolus hyalaculus Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, no. 7, p. 52, pl. 9, figs. 1-4. (67)

Astrononion gallowayi Loeblich and Tappan, 1953, *ibid.*, p. 90, pl. 17, figs. 4-7. (98)

Bolivina pseudoplicata Heron-Allen and Earland of Cushman and McCulloch, 1942, Allen Hancock Pacific Exped., vol. 6, no. 4, p. 204, pl. 25, figs. 4-7. A single specimen was found at station 72-9. The occurrence of this species may be due to contamination from the screens used with the Ro-Tap Automatic shaking machine. (99)

Bolivina subadvena Cushman var. *serrata* Natland, 1938, Bull. Scripps Inst. Oceanography, Tech. Ser., vol. 4, p. 145, pl. 5, figs. 8-9. (54)

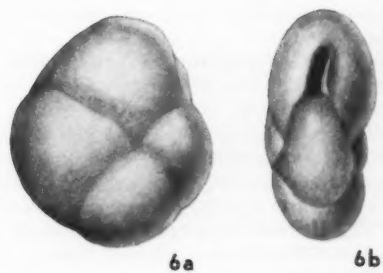
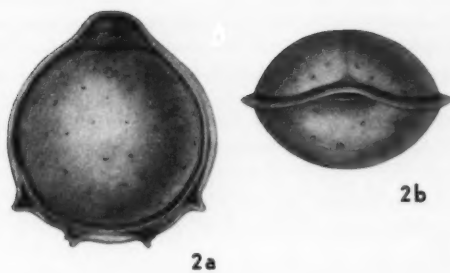
Bolivinita sp. (47)

Hyaline, biserial, finely perforate; test expanding gradually, straight or slightly curved, quadrate in section; chambers with secondary growth forming a disjointed keel along each edge of the test; chambers inclined downward from the center, forming an angle of 45° to 70° with the long axis of the test; chambers recurved near the center; sutures flush, limbate; aperture an arched opening at the base of the last chamber, at times surrounded by a horseshoe-shaped ring of secondary growth.

PLATE 1

- 1 *Ceratobulimina arctica* Green, n. sp.
Holotype (U.S.C. no. 4635): a, ventral view; b, edge view; c, dorsal view; × 142.
- 2 *Parafissurina arctica* Green, n. sp.
Holotype (U.S.C. no. 4625): a, ventral view; b, top view; × 111.
- 3 *Valvulinaria arctica* Green, n. sp.
Holotype (U.S.C. no. 4629): a, ventral view; b, edge view; c, dorsal view; × 25.

- 4 *Epistominella arctica* Green, n. sp.
Holotype (U.S.C. no. 4527): a, ventral view; b, dorsal view; × 250.
- 5 *Eponides tumidulus* (Brady) var. *horvathi* Green n. var.
Holotype (U.S.C. no. 4631): a, ventral view; b, edge view; c, dorsal view; × 166.
- 6 *Stetsonia horvathi* Green, n. sp.
Holotype (U.S.C. no. 4633): a, side view; b, apertural view; × 200.



- Buccella tenerrima* (Bandy) = *Rotalia tenerrima* Bandy, 1950, Jour. Pal., vol. 24, no. 3, p. 278, pl. 42, fig. 3. (49)
- **Bulimina aculeata* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 269. (40)
- Bulimina echinata* d'Orbigny, 1852, Prodrome Pal., vol. 3, p. 194. (45)
- Buliminella elegantissima* d'Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 51, pl. 7, figs. 13-14. (21)
- **Cassidulina icelandica* Norvang, 1945, The Zoology of Iceland, vol. 2, pt. 2, p. 41, figs. 7-8. (7)
- Cassidulina limbata* Cushman and Hughes, 1925, Contr. Cushman Lab. Foram. Res., vol. 1, p. 12, pl. 2, fig. 2. (60)
- **Cassidulina norcrossi* Cushman, 1933, Smithsonian Misc. Coll., vol. 89, no. 9, p. 7, pl. 2, fig. 7. (12)
- Cassidulina quadrata* Cushman and Hughes, 1925, Contr. Cushman Lab. Foram. Res., vol. 1, no. 1, p. 15, pl. 2, fig. 7. (26)
- **Cassidulina teretis* Tappan, 1951, Contr. Cushman Found. Foram. Res., vol. 2, pt. 1, p. 7, pl. 1, fig. 30. (1)
- **Ceratobulimina arctica* Green, n. sp. (pl. 1, fig. 1). (4)
- Chilostomella* sp. (85)
- Hyaline, finely perforate, test elongate, two chambers per whorl, embracing, final chamber making up half the length of the test, test slightly bent at the junction of the two chambers, circular in transverse section, earlier coils visible on the dorsal side of the test, aperture at times in complete specimens covered by a plate, opening parallel to the length of the test.
- Cibicides* sp. cf. *C. conoideus* Galloway and Wissler, 1927, Jour. Pal., vol. 1, no. 1, p. 63, pl. 10, fig. 7. (11)
- Cibicides lobatus* (d'Orbigny) 1839, in Barker-Webb and Berthelot, Hist. Nat. Îles Canaries, "Foraminifères," vol. 2, pt. 2, p. 134, pl. 2, figs. 22-24. (5)
- Cibicides wuellerstorfi* (Schwager) = *Anomalina wuellerstorfi* Schwager, 1866, Novara Exped. 1857-59, Geol. Theil, vol. 2, pt. 2, p. 258, pl. 7, figs. 105-107. (20)
- Cornuspira involvens* (Reuss) = *Operculina involvens* Reuss, 1850, Denkschr. Akad. Wiss. Wien, vol. 1, p. 370, pl. 46, fig. 20. (73)
- Cruciloculina japonica* Asano, 1949, Jour. Pal., vol. 23, no. 5, p. 480, pl. 81, figs. 1-2, 6-13. (32)
- Dentalina frobisherensis* Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, no. 7, p. 55, pl. 10, figs. 1-9. (77)
- Dentalina iitai* Loeblich and Tappan, 1953, *ibid.*, p. 56, pl. 10, figs. 10-12. (59)
- Discorbis* sp. A (71)
- Hyaline; rotaloid; finely perforate dorsally, coarsely perforate ventrally; color light yellow to brown; test concavo-convex with a high dorsal spire, margin sub-rounded and slightly lobulate; sutures ventrally radial, dorsally curved slightly backward, flush with the surface except near the periphery, where the sutures are depressed; umbilicus open, aperture obscured by broken tests.
- Discorbis* sp. cf. *D. rosacea* (d'Orbigny) = *Rotalia (Rotalia) rosacea* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 273; Modèles, no. 39. (76)
- Discorbina haliotideae* (Heron-Allen and Earland) = *Pulvinulina haliotideae* Heron-Allen and Earland, 1911, Roy. Micr. Soc., Jour., p. 338, pl. 11, figs. 6-11. (61)
- Elphidium bartletti* Cushman, 1933, Smithsonian Misc. Coll., vol. 89, no. 9, p. 4, pl. 1, fig. 9. (6)
- Elphidium incertum* (Williamson) = *Polystomella umbilicula* [(Walker and Jacob)] var. *incerta* Williamson, 1858, Recent Foraminifera of Great Britain, p. 44, pl. 3, fig. 82a. (91)
- Epistominella arctica* Green, n. sp. (pl. 1, fig. 4). (16)
- Epistominella* sp. B (103)
- Hyaline; rotaloid; finely perforate; small; biconvex, round in side view; edge subangular; periphery lobulate; chambers extending only halfway to the umbilicus on the ventral side, the central portion occupied by clear glassy shell material; sutures on the ventral side radial, dorsally slightly curved and tending to be tangential; aperture a high arched opening at the base of the last septal face, parallel with the periphery. Diameter 0.15-0.20 mm.
- Epistominella naraensis* (Kuwano) = *Pseudoparrella naraensis* Kuwano, Geol. Soc. Japan, Jour., vol. 56, no. 657, p. 317, pl. on p. 313, fig. 6. (3)
- Epistominella smithi* (Stewart and Stewart) = *Pulvinulinella smithi* Stewart and Stewart, 1930, Jour. Pal., vol. 4, p. 20, pl. 9, fig. 4. (90)
- Eponides pusillus* Parr, 1950, B.A.N.Z. Antarctic Res. Exped. 1929-31, Repts., Ser. B (Zool., Bot.), vol. 5, pt. 6, p. 360, pl. 14, fig. 16. (88)
- **Eponides tener* (Brady) = *Truncatulina tenera* Brady, 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 665, pl. 95, fig. 11. (17)
- **Eponides tumidulus* (Brady) var. *horvathi* Green, n. var. (pl. 1, fig. 5). (13)
- Fissurina* sp. A (86)
- Hyaline; unilocular; test compressed; oval, with the vertical axis the shortest, with a wide entire keel, the keel flattened at the bottom; finely perforate; aperture terminal, slightly curved, with an entosolenian tube extending to the bottom of the test.
- **Fissurina bassensis* Parr, 1950, B.A.N.Z. Antarctic Res. Exped. 1929-31, Repts., Ser. B (Zool., Bot.), vol. 5, pt. 6, p. 309, pl. 8, fig. 12. (39)
- Fissurina* sp. E (58)
- Hyaline; unilocular; finely perforate; test compressed, in side view rounded, keel rounded, either entire or lacking at the bottom; aperture fissurine, at the end of a short neck.
- Fissurina* sp. F (65)
- Hyaline; unilocular; finely perforate; test only slightly compressed, in side view round, becoming slightly pointed at the bottom end, edge round, translucent at the bottom to opaque at the top, aperture terminal, fissurine, with an irregular round entosolenian tube extending one-third the length of the test and attached to the chamber wall only at the end of the tube.
- Fissurina* sp. G (100)
- Hyaline; unilocular; finely perforate; test oval, compressed, wide rounded entire keel, aperture a fissurine slit, a short internal tube hanging free in the chamber.

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- Fissurina kerguelensis* Parr, 1950, B.A.N.Z. Antarctic Res. Exped. 1929-31, Repts., Ser. B (Zool., Bot.), vol. 5, pt. 6, p. 305, pl. 8, fig. 7. (50)
- Fissurina mennellae* (Buchner) = *Lagena mennellae* Buchner, 1940, K. Leop. Carol. Deutsch. Akad. Naturf., Abh. (Nova Acta), new ser., vol. 9, no. 62, p. 458, pl. 9, figs. 148-151. (69)
- Fissurina* sp. *O* (57)
Hyaline; unilocular; finely perforate; in side view oval, in cross-section compressed; keel entire, widening at the apertural end of the test; aperture fissurine.
- **Globigerina pachyderma* (Ehrenberg) = *Aristospira pachyderma* Ehrenberg, 1861, K. Preuss. Akad. Wiss. Berlin, Monatsber., p. 303; K. Akad. Wiss. Berlin, 1873 (1872), p. 223, pl. 1, fig. 4.
- Lagena* sp. *A* (52)
Hyaline; unilocular; finely perforate; test round and apiculate; twelve to sixteen costae run the entire length of the test; aperture at the end of a long ectosolenian tube, tube ornamented with four wide costae extending to the chamber only.
- Lagena alcocki* White, 1956, Jour. Pal., vol. 30, no. 2, p. 246, pl. 27, fig. 7. (31)
- Lagena amorpha* Reuss, 1863, K. Akad. Wiss. Wien, Math-Naturw. Cl., Sitzber., vol. 46, pt. 1 (1862), p. 330. (46)
- Lagena meridionalis* Wiesner, 1931, Deutsche Südpolar-Exped. 1901-03, vol. 20 (Zool., vol. 12), p. 117, pl. 18, fig. 211. (51)
- **Lagena* sp. *E* (53)
Hyaline; unilocular; finely perforate; test tear-shaped, compressed, heavily ornamented with costae, pits, and pustules arranged in neat orderly vertical patterns; aperture at the end of an ectosolenian tube, with a phialine lip.
- Lagena* sp. *H* (79)
Hyaline; unilocular; finely perforate; test spherical, with hexagonal ornamentation on the upper surface of the test as in *Lagena hexagona*, the hexagonal ornamentation becoming elongate on the lower surface of the test and extending to three rings around the ectosolenian tube leading to the aperture.
- Lagena hexagona* (Williamson) = *Entosolenia squamosa* (Montagu) var. *hexagona* Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, vol. 1, p. 20, pl. 2, fig. 23. (36)
- Lagena hispida* Reuss, 1863, K. Akad. Wiss. Wien, Math-Naturw. Cl., Sitzber., vol. 46, pt. 1 (1862), p. 335. (101)
- Lagena* sp. *J* (62)
Hyaline; unilocular; finely perforate; test elongate, straight or curved, circular in cross-section, no ornamentation; aperture at the end of an ectosolenian tube.
- Lagena* sp. *K* (96)
Hyaline; unilocular; coarsely perforate; the single chamber has twelve sides that are in the form of two six-sided pyramids with the bases of the pyramids attached to one another; hispid ornamentation; aperture a simple terminal opening.
- Lagena* sp. *P* (44)
Hyaline; unilocular; finely perforate; test ovate, circular in cross-section; aperture at the end of a short ectosolenian tube.
- Lagena squamosa-sulcata* Heron-Allen and Earland, 1922, British Antarctic Exped. 1910, Nat. Hist. Rept., Zool., vol. 6, no. 2, p. 151, pl. 5, figs. 15, 19. (68)
- Lagena* sp. *T* (48)
Hyaline; unilocular; finely perforate; test spherical with sixteen to twenty low costae, lower portion of the test free of ornamentation with the exception of a short spine; aperture a simple opening on the upper surface of the test, without a neck.
- Lagena* sp. *X* (83)
Hyaline; unilocular; test tear-shaped, with eighteen to twenty vertical rows of hispid spines; aperture terminal, at the end of the ectosolenian tube.
- Miliolinella circularis* (Bornemann) = *Triloculina circularis* Bornemann, 1855, Deutsch. Geol. Ges., Zeitschr., vol. 7, no. 2, p. 349, pl. 19, fig. 4. (10)
- Nodosaria* sp. (87)
Hyaline; uniserial; finely perforate; six to eight chambers in the unbroken adult specimen; ten to thirteen low costae extending across the sutures for the length of the test; sutures depressed; aperture terminal, radiate.
- **Nonion affinis* (Reuss) = *Nonionina affinis* Reuss, 1851, Deutsch. Geol. Ges., Zeitschr., vol. 3, pp. 72, pl. 5, fig. 32. (41)
- Nonionella miocenica* Cushman var. *stella* Cushman and Moyer, 1930, Cushman Lab. Foram. Res., Contr. vol. 6, p. 56, pl. 7, fig. 17. (95)
- **Nummuloculina* sp. (2)
Porcellaneous; planispiral; initial chamber large, with a second chamber extending for a distance of one-half to one coil; in some specimens a third chamber is added planispirally; aperture a simple opening at the end of the tubular second or third chamber.
- Oolina* sp. *A* (38)
Hyaline; unilocular; finely perforate; test spherical; slightly opaque; eighteen to twenty-two striae extending from a small spine at the base of the test approximately one-half the length of the test; aperture slightly elevated above the test, with an internal tube three-fourths the length of the test, the tube hanging free in the chamber.
- Oolina* sp. *B* (66)
Hyaline; unilocular; finely perforate; test spherical; opaque; ornamentation absent except for a spine at the base of the test; aperture elevated above the surface of the test and slightly excentric from the spine; entosolenian tube extending half the length of the test and hanging free in the chamber.
- Oolina* sp. *C* (92)
Hyaline; unilocular; finely perforate; test spherical, opaque; sixteen to twenty vertical costae extending from the aperture to the base of the test, a small spine at the base of the test; aperture with a phialine lip and entosolenian tube hanging free in the chamber.
- Oolina melo* d'Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 20, pl. 5, fig. 9. (35)

- Oolina scalariformis* (Williamson) = *Entosolenia squamosa* (Montagu) var. *scalariformis* Williamson, 1848, Ann. Mag. Nat. Hist., ser. 2, vol. 1, p. 20, pl. 2, figs. 21–22. (78)
- Ophthalmidium* sp. (70)
Porcellaneous; planispiral; test flat, biconcave, initial chamber large, followed by a second chamber of several volutions; second chamber quite involute as compared with later chambers; the later chambers added irregularly up to two per whorl; aperture a simple opening at the end of the last chamber.
- **Parafissurina arctica* Green, n. sp. (pl. 1, fig. 2). (23)
Parafissurina arctica Green var. *Y* (93)
Hyaline; unilocular; finely perforate; test round in side view, compressed in cross-section; thick, sharp keel with three well-developed spines, one spine at each side and one at the bottom; entosolenian tube attached and making one complete volution; aperture beneath a curved plate. This single specimen is sufficiently different from *P. arctica* that it has been designated as a variety; the spines are placed and much better developed, the entosolenian tube makes a complete volution, and the size is smaller.
- **Parafissurina curta* Parr, 1950, B.A.N.Z. Antarctic Res. Exped. 1929–30, Repts., ser. B (Zool., Bot.), vol. 5, pt. 6, p. 318, pl. 10, figs. 6–7. (29)
Parafissurina sp. *F* (55)
Hyaline; unilocular; test elongate quadrate, round in section; aperture hooded. (55)
- Parafissurina fusuliformis* Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, no. 7, p. 79, pl. 14, figs. 18–19. (64)
- Parafissurina subcarinata* Parr, 1950, B.A.N.Z. Antarctic Res. Exped. 1929–30, Repts., ser. B (Zool., Bot.), vol. 5, pt. 6, p. 318, pl. 10, fig. 9. (75)
- Parafissurina subulata* Parr, 1950, *ibid.*, vol. 5, pt. 6, p. 319, pl. 10, fig. 11. (27)
- Patellina corrugata* Williamson, 1858, Recent Foraminifera of Great Britain, p. 46, pl. 3, figs. 86–89. (22)
- Pateoris hauerinoides* (Rhumbler) = *Quinqueloculina subrotunda* (Montagu) forma *hauerinoides* Rhumbler, 1936, Kieler Meeresforsch., vol. 1, no. 1, pp. 206, 217, 226, figs. 167, 208–212. (34)
- Planispirinoides bucculentus* (Brady) = *Miliolina bucculenta* Brady, 1884, Rept. Voy. Challenger, Zool., vol. 9, p. 170, pl. 114, fig. 3. (37)
- Pullenia bulloides* d'Orbigny, 1846, Foraminifères fossiles du bassin Tertiaire de Vienne, p. 107, pl. 5, figs. 9–10. (43)
- Pyrgo bulloides* (d'Orbigny) var. *calostoma* (Karrer) = *Biloculina bulloides* d'Orbigny var. *calostoma* Karrer, 1868, K. Akad. Wiss. Wien, Math-Naturw. Cl., Sitzber., vol. 58, pt. 1, p. 132, pl. 1, fig. 4. (104)
- Pyrgoella elongata* (d'Orbigny) = *Biloculina elongata* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 298. (14)
- Prygoella sphaera* (d'Orbigny) = *Biloculina sphaera* d'Orbigny, 1839, Voy. Amér. Mérid., Foraminifères, vol. 5, pt. 5, p. 66, pl. 8, figs. 13–16. (80)
- Quinqueloculina akneriana* d'Orbigny, 1846, Foraminifères fossiles du bassin Tertiaire de Vienne, p. 290, pl. 18, figs. 16–21. This form in the Arctic Basin is quite variable in section and ornamentation. The cross-section varies from subrounded to angular, and the test varies from smooth to highly costate. (18)
- **Quinqueloculina* sp. (28)
Porcellaneous; five chambers visible externally, four from one side, three from the other; test elongate in outline; chamber margins sharply acute and curved backward in section; aperture circular, with no projecting neck and no tooth.
- Raphanulina gutta* (d'Orbigny) = *Polymorphina (Pyraline) gutta* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 267, pl. 12, figs. 5–6. (89)
- Rectobolivina hancocki* (Cushman and McCulloch) = 1942, Allan Hancock Pacific Exped., vol. 6, no. 4, p. 225, pl. 28, figs. 14–19. The single occurrence of this species at station 72–9 is probably due to contamination. (102)
- Reophax* sp. (33)
Arenaceous; uniserial; test smooth; clear quartz crystals cemented with a large amount of orange-brown cement; chambers inflated, widest just above the base of the chamber in the last few chambers, earlier chambers widest near the middle of the chamber, initial chamber broadly rounded; sutures depressed; aperture terminal, an irregular opening.
- Robertina (Robertinoides) charlottensis* (Cushman) = *Cassidulina charlottensis* Cushman, 1925, Contr. Cushman Lab. Foram. Res., vol. 1, no. 1, p. 41, pl. 6, figs. 6–7. (24)
- Robertina (Robertina) subcylindrica* (Brady) = *Bulimina subcylindrica* Brady, 1881, Quart. Jour. Micr. Sci., new ser., vol. 21, p. 56. (63)
- Rotorbinella versiformis* (Bandy) = *Rotalia versiformis* Bandy, 1953, Jour. Pal., vol. 27, no. 2, p. 179, pl. 22, fig. 5. (30)
- Sigmoilina tenuis* (Czjzek) = *Quinqueloculina tenuis* Czjzek, 1848, Naturw. Abh., vol. 2, pt. 1, p. 149, pl. 13, figs. 31–34. (72)
- **Spirillina vivipara* Ehrenberg, 1843, K. Akad. Wiss. Berlin, Abh., Jahrg. 1841, pt. 1, pp. 323, 422, pl. 3, VIII, fig. 41. (74)
- **Stetsonia horvathi* Green, n. sp. (pl. 1, fig. 6). (19)
- Triloculina tricarinata* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, vol. 7, p. 299; Modèles, no. 94. (84)
- Triloculina trihedra* Loeblich and Tappan, 1953, Smithsonian Misc. Coll., vol. 121, no. 7, p. 45, pl. 4, fig. 10. (15)
- Trochammina globigeriniformis* (Parker and Jones) = *Lituola nautiloidea* (Lamarck) var. *globigeriniformis* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., vol. 155, p. 407, pl. 15, figs. 46–47; pl. 17, figs. 96–98. (82)
- Trochammina nana* (Brady) = *Lituola (Haplophragmium) nanum* Brady, 1881, Quart. Jour. Micr. Sci., vol. 21, p. 50. (9)
- Trochammina rotaliformis* Wright, 1911, in Heron-Allen and Earland, Jour. Roy. Micr. Soc., p. 309. (81)

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- Turrispirillina arctica* (Cushman) = *Spirillina arctica* Cushman, 1933, Smithsonian Inst. Misc. Coll., vol. 89, no. 9, p. 6, pl. 2, fig. 1 (not fig. 2). (56)
- **Valvulineria arctica* Green, n. sp. (pl. 1, fig. 3). (8)
- Virgulina nodosa* Stewart and Stewart, 1930, Jour. Pal., vol. 4, p. 64, pl. 8, fig. 4. (25)
- Virgulina* sp. cf. *V. tessellata* Phleger and Parker, 1951, Geol. Soc. Amer., Mem., no. 46, pt. 2, p. 19. (42)
- Vulvulina* sp. (94)
- Arenaceous; planispiral with uniserial rectilinear terminal portion; large; four chambers in the last coil, five chambers in the rectilinear series; large sand grains cemented with little cement; aperture terminal, elliptical, with a thickened rim.

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ABSTRACT: *The discovery of fossil opal-phytoliths in several Tertiary and Quarternary sediments of Victoria shows that they resisted mechanical and chemical weathering during deposition. They survived several million years without being severely corroded or transformed by hydration to either chalcedony or quartz during the diagenesis of sedimentation. Fossil as well as recent plants secreted opal-phytoliths. Their presence in sediments serves as an indicator of certain plant groups, grasses, reeds and their allies, where recognizable remains or macerated debris did not survive.*

Fossil opal-phytoliths

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INTRODUCTION

The recent discovery (Baker, 1959a, 1959b) that most of the minute opaline silica bodies in Victoria soils are in reality opal-phytoliths and not sponge spicules as formerly believed, led to the search for fossil opal-phytoliths.

The object of the search was to determine whether opal-phytoliths survived processes of transportation and sedimentation, and ultimately were preserved in the fossil state under conditions which differ from those normally extant in present day soils. It was hoped to demonstrate that the variety of shapes-types of opal-phytoliths which are released on decomposition from the modern plants in Victoria could also be found in soils dating from the Tertiary to the Holocene.

In sampling and preparing the specimens for microscopic examination, every care was taken to eliminate contamination by recent phytoliths. Outer surfaces of the hand specimens were scraped away and discarded, so that any superficially attached opal-phytoliths of recent origin were thus rejected. Distilled water was used exclusively in all stages of preparation to avoid the introduction of stray phytoliths in tap water (Baker, 1959a, pp. 68 and 81).

So far, the search for opal-phytoliths was successful in five of the six specimens examined from Tertiary and Quarternary sediments. This establishes the occurrence of opal-phytoliths in the fossil state, and proves that a proportion of them can withstand transportation and sedimentation and can also survive post-depositional changes that are likely to occur after burial.

Fossil opal-phytoliths have now been detected in a wide variety of sediments: diatomaceous earth of Holocene age from Western Victoria; diatomaceous silty clay of Holocene age from Western Victoria; calcareous-kaolinitic earthy sediment of upper Pleistocene age from near Melbourne, Victoria; grey dense clay of upper Pliocene age from far Western Victoria; and non-consolidated, fine quartz sand (arenite) of probably Paleocene age from a deep bore in Western Victoria.

OCCURRENCE

Diatomaceous earth (Holocene)

A sample of "soil" collected by F. R. Gibbons, of the Soil Conservation Authority, was obtained from Allotment 69A, parish of Dunmore, county Normandy, Western Victoria. The grid reference of this locality on the Heywood Military Sheet is 823,037. The area is situated on the eastern side near the former shores of Lake Condah (recently drained), in a region of exceptionally well-developed, young stony rises in Newer Basalt country. The "soil" occurs in shallow depressions among the stony rises, and was evidently deposited less than 10,000 years ago.

The sample was separated into a +10 micron fraction and a -10 micron fraction in the Agricultural Chemistry Department, University of Melbourne. The +10 micron fraction submitted to the author contains abundant diatoms and significant amounts of silicisponge spicules and opal-phytoliths.

Subsequent examination of the -10 micron fraction of a sample collected later from the same locality, revealed that it is constituted largely of fragments

of the components already observed in the +10 micron fraction. The substance is thus diatomaceous earth rather than "soil".

Hand specimens are light buff-coloured, light in weight, somewhat unctuous, friable and porous. The sediment is essentially a biochemical deposit in which opaline frustules of diatoms are dominant and silicisponge spicules fairly common. These are accompanied by approximately 11 per cent of opal-phytoliths, a smaller quantity of detrital mineral particles, and occasional opal fragments of nondescript shape which are evidently of biochemical origin but are not recognisable fragments of either diatoms, silicisponge spicules or opal-phytoliths.

Particle counts of the +10 micron fraction, which constitutes 6.5 per cent of the diatomaceous earth, reveal the proportions of constituents listed in Table 1, column 1.

TABLE 1
PROPORTIONS BY COUNT OF THE MAJOR CONSTITUENTS
IN THE + 10 MICRON FRACTION OF DIATOMACEOUS
EARTH AND SILTY CLAY FROM LAKE CONDAH, WESTERN
VICTORIA.

Constituents	1 (%)	2 (%)
Diatom frustules	64	22
Silicisponge spicules	19	6
Opal-phytoliths	11	4
Detrital mineral particles*	6	68
Total	100	100
Number of particles counted	520	805

* — including a number of fragments of opal of biochemical origin not assignable to either diatoms, silicisponge spicules or opal-phytoliths.

1 — Diatomaceous earth from eastern side of Lake Condah (now drained), Western Victoria.

2 — Diatomaceous silty clay, east bank of main drainage channel, Breakaway Creek Road bridge, Lake Condah district, Western Victoria.

The mineral particles of detrital origin listed in Table 1, column 1 consist largely of quartz grains up to 0.15 mm. in size. Occasional opaque black minerals are present, and a few of the opal-phytoliths are opaque grey. The —10 micron fraction contains particles too small for assessment of the approximate proportions of each type present.

Some of the characteristic shapes of the opal-phytoliths in the +10 micron fraction are shown in text-figure 1. The sketches represent the outline

appearances of the opal-phytoliths as they settled in natural positions of rest in the mounting medium, and many of them are a little thinner than the widths shown in the sketches.

The most abundant forms are rod-like, several of which are approximately equidimensional normal to the long axis. Several of the rods have relatively smooth surfaces and smooth edges; some are serrated along one or sometimes both of their longer edges, others have crenulated outlines. A few of the rods taper and then assume an elongated cuneate form.

For comparison with recent opal-phytoliths, it is worth noting that some rod-like forms with typically smooth longer edges are solid internal casts of the long, narrow sub-epidermal cells in living members of the grass tribe. On the other hand, rods with crenulated and serrated longer edges are characteristically solid internal casts of the wavy-edged epidermal cells in the grass tribe. They are forms that completely infill some but not all cells in the living grasses and allied types, and are thus essentially cytolith (i.e. cell-infilled) examples of opal-phytoliths.

Some rods among the fossil opal-phytoliths are more crenulated and rather more slender (text-fig. 1, no. 12) than others and appear almost "corkscrew-like". Occasional rods are deeply crenate (text-fig. 1, no. 32), several are emarginate (text-fig. 1, nos. 11 and 17), and some of the longer rods tend to be ensiform (text-fig. 1, no. 3). Rods with apparent bends as in the example shown in text-fig. 1, no. 2, were observed *in situ* in the epidermal cells of living species of *Poa*. The pronounced bend and concavity on the right-hand-side of this type of rod, is where oval-shaped cells (stoma) intervene in the epidermis.

A few of the rods are rather irregular in outline, but no more so than several of the rod-shaped opal-phytoliths generated by present day plants, hence it is difficult to prove whether any of these types were much corroded after release from the host plants. In general, the whole assemblage of fossil opal-phytoliths in the diatomaceous earth appears to be well-preserved. The only examples that can be regarded as definitely having been subjected to a degree of chemical corrosion, are the few forms which reveal microscopically roughened surfaces interpreted as due to minute etch-pitting (text-fig. 1, nos. 15, 20, 21, 46 and 47). The sculpture pattern so produced is not matched on any of the opal-phytoliths observed *in situ* in living plants. In a few of the fossil forms, etch pitting has been superposed on the initial sculpture patterns proper to

FOSSIL OPAL-PHYTOLITHS

newly generated opal-phytoliths. The incidence of etch pitting of fossil opal-phytoliths is no more frequent than that found in the opal-phytoliths of some present day soils, and no estimate can be made of the numbers that may have been completely dissolved from sediments known to contain some opal-phytoliths.

Other forms present (text-fig. 1, nos. 16, 22, 25, 33, 39, 41 and 42) are comparable with portions of the hook-like and spine-like opal-phytoliths observed on living plants and present day soils. As seen in living grasses and allied forms such as sedges and reeds, hook-like and spine-like opal-phytoliths are partially embedded in the outer epidermal cells with their sharper and more pointed distal ends projecting outwards and sometimes downwards. They impart a harsh feel to certain species of the grass tribe. As observed in present day soils, many of the hook-like and spine-like opal-phytoliths have rounded tips, or else the sharp ends have been broken off; fossil examples of these types (text-fig. 1) are frequently rather more modified as a result of abrasion during transportation to the site of deposition. The secondarily modified fossil forms, however, still retain outlines (text-fig. 1, nos. 25 and 27) which definitely relate them to similar forms developed in living grasses, even though they have lost their sharp distal ends and practically all vestiges of the small, delicate protuberances that constitute minor, but important, features of recently generated hook-like opal-phytoliths. In living grasses, these small protuberances assist in anchoring the main body of the hook-shaped opal-phytolith in the outermost epidermal cells, since they connect with thin films of opaline silica lining the walls of some epidermal cells.

Occasional of the fossil opal-phytoliths are berry-like (text-fig. 1, nos. 46 and 47). Others are elongated oval-shaped forms (text-fig. 1, nos. 15 and 16) which sometimes resemble the underneath aspects of some of the hook-like opal-phytoliths; they sometimes reveal the eroded remnants of pre-existing small protuberances. Some forms are hat-shaped (text-fig. 1, no. 24), boat-shaped (text-fig. 1, no. 23), or nondescript in shape (text-fig. 1, nos. 20, 21 and 36). Rare examples of cell-linings and cell wall-replacements (Baker, 1959c) have also been observed.

Some of the forms (text-fig. 1, nos. 5, 9, 16, 37 and 41) are opaque and light grey in reflected light.

The generally excellent state of preservation of most of these fossil opal-phytoliths in a diatomaceous earth of Holocene age, points to either short distances of transportation into the freshwater lake as inde-

pendant and free entities, or, if carried for longer distances by streams or air currents, as opal bodies still locked up in particles of plant debris. In view of the low contents of detrital mineral particles in the diatomaceous earth, it is possible that many of the opal-phytoliths were shed directly into the lake waters from grasses, reeds and sedges growing in the lake or around its fringe. Those still incorporated in fragments of dead plants would ultimately be released on decomposition of the organic matter, and hence need not have suffered any attrition whatsoever.

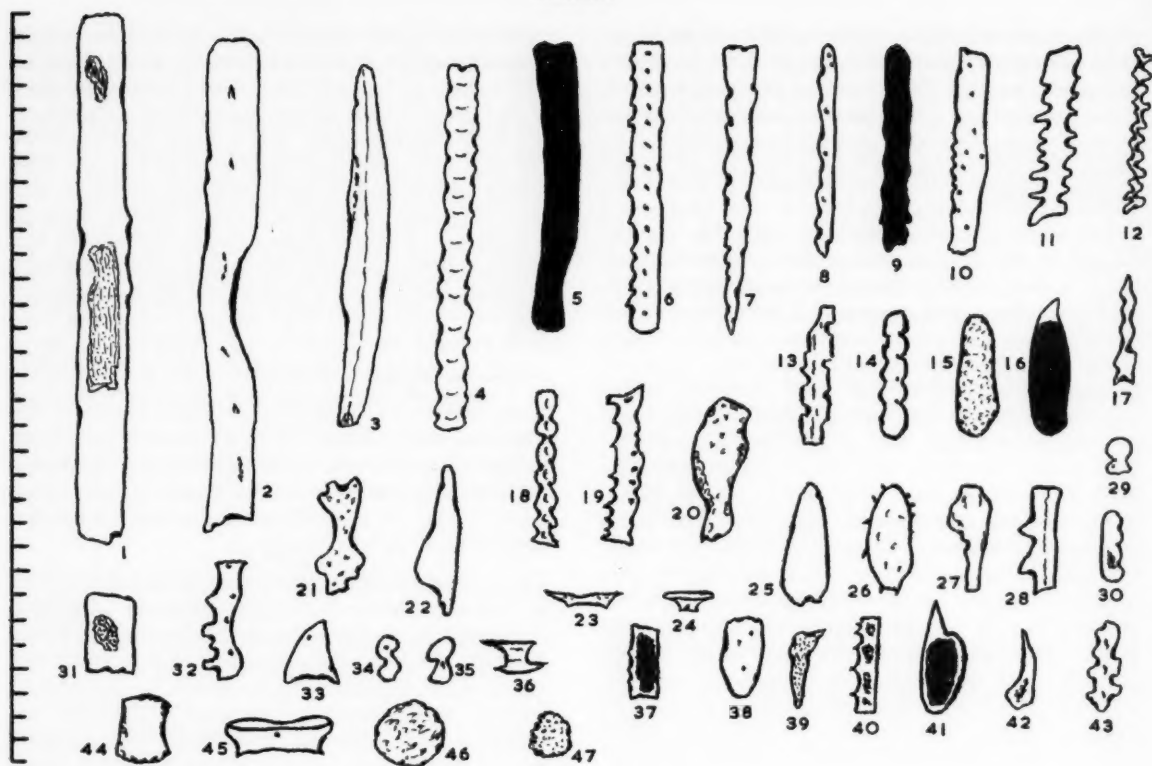
Diatomaceous silty clay (Holocene)

In diatomaceous silty clay of Holocene age from the main drainage channel at Breakaway Creek Road bridge, Lake Condah region, Western Victoria, opaline silica bodies are only approximately one-third as frequent as in diatomaceous earth from the same general district (Table 1).

The sample examined was collected four feet below the surface from a vertical exposure of silty clay outcropping on the eastern banks of the main drainage channel. Here the silty clay is about six feet thick and overlies Newer Basalt; it contains a layer of small freshwater gastropods situated one foot below the surface of the outcrop. Both diatoms and silicisponge spicules are more abundant than opal-phytoliths, but none of these opaline bodies are as common as in the diatomaceous earth from Lake Condah.

The principal forms of the opal-phytoliths are rods with crenulate outlines and rods with smooth outlines, regarded as having been derived from epidermal cells in plants of the grass tribe. They range in size from 0.20 mm. long by 0.02 mm. wide down to 0.025 mm. long by 0.010 mm. wide. Other forms present are fragments from cell-linings which occur as thin plates indicative of minor amounts of amorphous silica precipitation on the walls of plant cells. Rare fragments of cell-wall replacements preserve in detail certain portions of original cell structures. Hat-shaped forms are rare, and with the other shape types represented, are generally comparable with examples illustrated from the Lake Condah diatomaceous earth (text-fig. 1). A few of the fossil opal-phytoliths are opaque and light grey in reflected light. Some have a rugose appearance due to the development of numerous small etch pits from corrosion.

The proportions of diatoms, silicisponge spicules and opal-phytoliths listed in Table 1, column 2, were determined from particle counts that excluded minute particles under 0.001 mm. in size. Many of



TEXT-FIGURE 1

Numbers 1 to 47 - outline sketches of opal-phytoliths from Holocene diatomaceous earth, Allotment 69A, parish of Dunmore, county Normandy, Western Victoria. Each scale graduation represents 0.010 mm.

the diatoms, most of the silicisponge spicules and several of the opal-phytoliths have been broken, apparently largely by fracturing during transportation and sedimentation. The silt and clay size particles in the sediment consist principally of clay minerals with some quartz and a number of small fragments of opal.

Calcareous-kaolinic earth (upper Pleistocene)

A variety of fossil opal-phytoliths (see fig. 2) occurs in a calcareous-kaolinic earthy deposit from Fowler's Quarry, Steele Creek, Niddrie (West Essendon), near Melbourne, Victoria. The sediment sampled by Mr. E. D. Gill is regarded as upper Pleistocene in age.

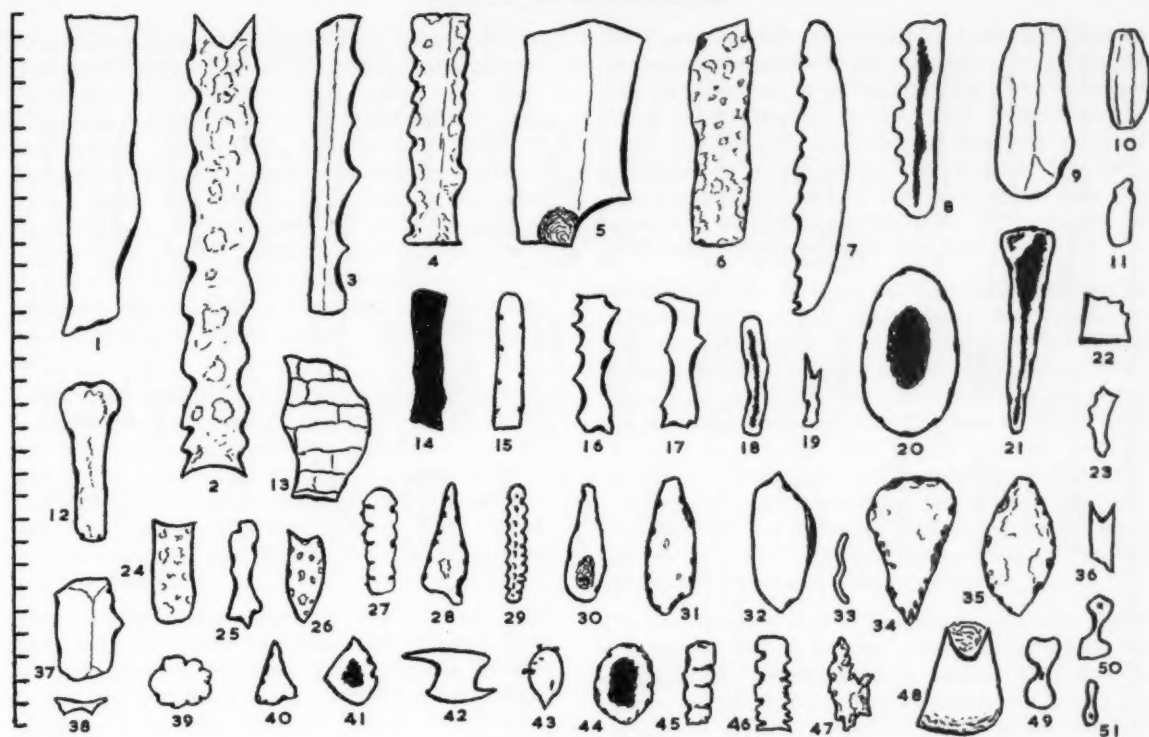
Rod-shaped opal-phytoliths are again the most common forms; some have smooth and others have crenulated longer edges (text-fig. 2, no. 2). Cell-

linings, complex cell-wall replacements, hatchet-shaped, hook-like, dumbbell-shaped, oval and spearhead-shaped forms are also represented among a number with nondescript shapes.

A few of the rods are strongly etched from corrosion (text-fig. 2, no. 6) and many of the different shape types are more irregular in outline and rather more markedly etched than opal-phytoliths hitherto observed in Victorian soils. Compared with the silicisponge spicules present, the opal-phytoliths are notably more worn, suggesting greater amounts of abrasion due to longer distance of transportation to the area of sedimentation.

A count of approximately 500 particles of opaline silica in the —0.20 mm. size fraction, revealed that the sediment contained the following proportions: diatoms / silicisponge spicules / opal-phytoliths:: 6 / 10.5 / 3.5.

FOSSIL OPAL-PHYTOLITHS



TEXT-FIGURE 2

Numbers 1 to 51 - outline sketches of fossil opal-phytoliths from upper Pleistocene calcareous - kaolinitic earthy sediment at Fowler's Quarry, Steele Creek, Niddrie (West Essendon), near Melbourne, Victoria. Heavily shaded areas appear almost opaque under the microscope and are light grey in reflected light. Each scale graduation represents 0.010 mm.

Grey clay sediment (upper Pliocene)

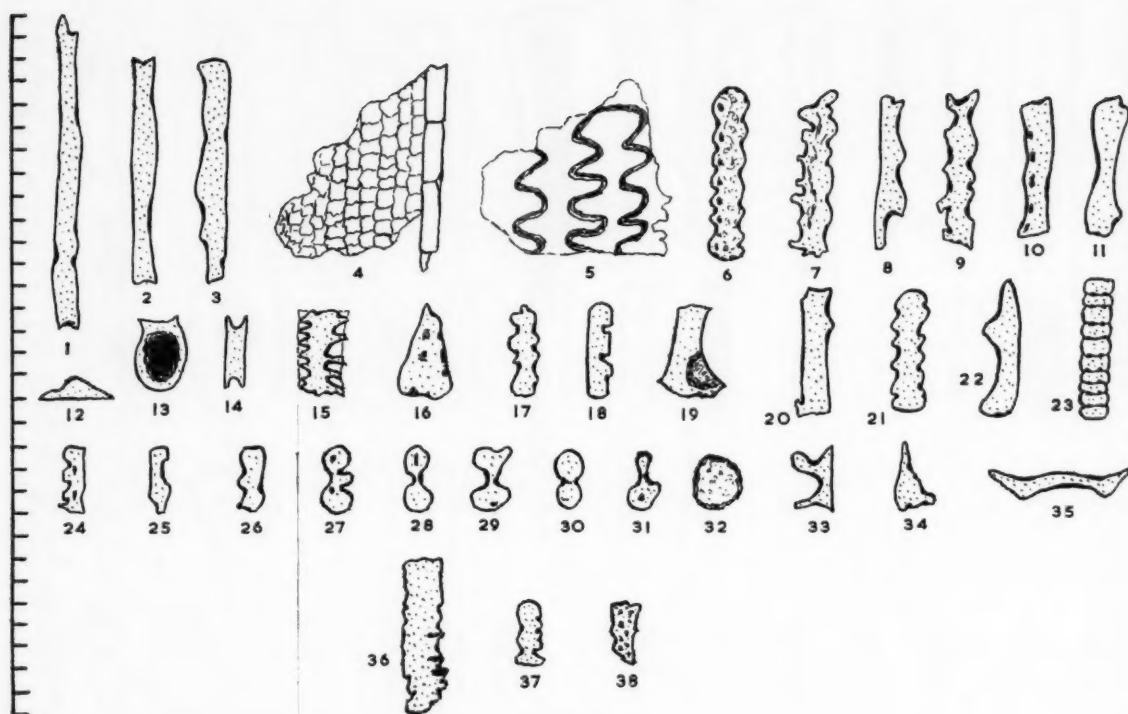
A clay sediment with a small content of diatoms, collected by Mr. E. D. Gill from underneath the basalt at Grange Burn, near Hamilton, Western Victoria, is a freshwater deposit regarded as upper Pliocene in age (Gill, 1953, p. 151). The diatoms have been determined by Mr. B. Tindale (1953, pp. 138-139), and numerous silicisponge spicules were noted. Examination of Mr. Tindale's preparations (three microscope slides, register numbers 15249 to 15251 in the fossil collection of the National Museum of Victoria) revealed opal-phytoliths (text-fig. 3) among the assemblage of opaline bodies, and also fragments of opal that could not be assigned to either diatoms, silicisponge spicules or opal-phytoliths.

A count of 1,040 particles of opal including opaline bodies and opal fragments in the concentrate prepared from the clay sediment by Mr. Tindale, and from which most other mineral matter has been

eliminated, revealed the following proportions : opal fragments / opal-phytoliths / diatoms / silicisponge spicules 89.5 / 6.2 / 2.9 / 1.4.

Several of the opal-phytoliths are corroded and worn, but many are reasonably well-preserved. The shape types are not as varied as in present day soils (Baker, 1959a, 1959b), probably because corrosion has completely removed some examples or rendered them unrecognisable as opal-phytoliths during their longer period of entombment in the clay sediment. Nevertheless, those still preserved prove that upper Pliocene species of the grass tribe supplied opal-phytoliths that were carried in to freshwater sediments in the Grange Burn district.

Rod-shaped forms are relatively common, some with smooth and some with crenulated longer edges (text-fig. 3). Occasional rods resemble elongated wedges in being tapered and flatter in cross section towards one end, while the other end is rectangular



TEXT-FIGURE 3

Numbers 1 to 35 – outline sketches of opal-phytoliths from upper Pliocene grey clay sediment beneath basalt at Grange Burn, near Hamilton, Western Victoria. Numbers 36 to 38 – from Paleocene non-consolidated fine quartz sand (arenite) at 4,506 feet in the Nelson Bore, near mouth of Glenelg River, Western Victoria. The sketches are lightly stippled to indicate that most examples have been corroded superficially and show minute etch pits. Each scale graduation represents 0.010 mm.

or elliptical to circular in cross section. Other forms encountered are berry-like (text-fig. 3, no. 32) and average 0.015 mm. in diameter. Some are boat-shaped (text-fig. 3, no. 35), dumbbell-shaped (text-fig. 3, nos. 27 to 31), hatchet-shaped (text-fig. 3, no. 19) or hook-like (text-fig. 3, no. 34).

More complex opal-phytoliths (text-fig. 3, nos. 4, 5 and 15) consist of aggregates of plant cells preserved in detail by opaline silica replacements. From analogy with those observed in present day soils (Baker, 1959a, 1959b) and living plants, such complex structures were developed within the plant, and are not a result of subsequent metasomatic replacement in a geological milieu.

The irregular plates and fragments of opal that are rather larger than usual and show no evidence relating them to fragments of any of the opaline organisms, were evidently derived mostly from biochemical precipitation in the area of sediment

accumulation, or partially from post-depositional changes in the sediment, since some of them contain inclusions of detrital quartz and zircon. Some of the other opal fragments that are free from included detrital mineral particles could possibly have been derived from portions of plants that were more extensively opalised than normally, but this is not substantiated.

The opal-phytoliths are detrital to the sediment, having been shed from the upper Pliocene plants in which they were secreted, and subsequently washed (or blown) into an area of freshwater sediment accumulation, either as completely freed entities or still entrapped in plant fragments.

Non-consolidated fine quartz sand (Paleocene)

A few opal-phytoliths and silicisponge spicules have been detected in the light fraction of a fine quartz sand sediment (arenite) from 4,506 feet in the

FOSSIL OPAL-PHYTOLITHS

Nelson Bore, near the mouth of the Glenelg River, Western Victoria. The silicisponge spicules characteristically show axial canals, while the opal-phytoliths are typically solid rods with outlines indicated in text-figure 3, nos. 36 to 38. A few of the rods reveal little evidence of corrosion or abrasion, others show etch-pitting, while small, irregular fragments of opal approximately 0.015 mm. in size appear to have been fractured from opal-phytoliths during transportation. The largest rod-shaped form observed, measures 0.075 mm. long and 0.025 mm. wide and has crenulate longer edges (text-fig. 3, no. 36).

Since these opal-phytoliths occur in a non-consolidated sediment recovered from a bore, the possibility arises that they may have been introduced from the water and muds used in boring operations. The abraded character of some and the strong etch-pitting of others, however, indicate some considerable antiquity, and favour their being original to the sediment.

Small rod-like opal-phytoliths ranging from 0.025 mm. long and 0.006 mm. wide to 0.030 mm. long and 0.015 mm. wide, occur in the $\frac{1}{8}$ mm. fraction of the light constituents of a partially cemented fine sand (arenite) from 3,955 feet in the Nelson Bore. They also are most likely original to the sediment rather than contamination products, more especially as the sediment is lightly cemented.

If most of the opal-phytoliths are genuinely part of the sediments from the Nelson Bore, then they are the oldest fossil representatives so far detected. Their sparseness could be accounted for by considerable distance from their primary source and the fact that they are in types of sediments which indicate shallow-water, near-shore environments (cf. Baker, 1959d), where the concentration density of such minute objects washed in from the land is likely to be very low, and loss of identity by solution during a long period of burial (approximately 60 to 70 million years).

CONCLUSIONS

The discovery that opal-phytoliths occur in several sediments of different age in the Tertiary and Quaternary periods in Victoria, proves that they can survive transportation and become preserved in the fossil state for varying periods of time ranging back to the Paleocene. The forerunners of present day phytolith-generating plants also secreted opal in similar forms to those observed in living plants and present day soils; the process of phytolith-generation has therefore continued for several millions of years.

Furthermore, the occurrence of opal-phytoliths in the sediments points to the existence of certain types of vegetation in the several terrains, even when no other plant remains persist. The resemblance of fossil rod-like and hook-shaped opal-phytoliths to examples in living plants and present day soils, indicates that plants of the grass tribe were responsible for secreting opal in these shapes in Holocene, Pleistocene and Pliocene.

Opal-phytoliths do not seem to persist for more than approximately 1,000 years under the conditions prevalent in present day soils in Victoria, before being taken into solution (Baker and Leeper, 1958; Baker, 1959a, 1959c); the pH of the soils is such as to keep the opal-phytolith population down to a level of from 1 per cent to 2.5 per cent in soils generally. Under geological conditions, however, where they can sometimes be sealed relatively rapidly and thus protected from attack by the more severe corrosive agents, some examples can be preserved for several millions of years.

In the Tertiary and Quaternary sediments so far examined for their opal-phytolith contents in Victoria, no phytoliths were detected that showed signs of conversion from amorphous (opal) to cryptocrystalline (chalcedony) or crystalline (quartz) silica. Given the right conditions for dehydration, such conversion might be expected among the fossil opal-phytoliths observed in the older Tertiary sediments. If such a process has occurred, the newly formed products have not retained any shapes that would identify them with the original forms of opal-phytoliths.

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ABSTRACT: *A preliminary survey of the stratigraphy, paleoecology, and micropaleontology of the Cretaceous and lower Tertiary rocks of southwestern Puerto Rico is presented. A local system of zonation based on planktonic foraminifera is proposed for the Campanian and Maestrichtian. The stratigraphy and paleoecology of the major formational units are briefly discussed. Six new species and one new subspecies are described.*

Stratigraphy and micropaleontology of the Cretaceous and lower Tertiary of Puerto Rico

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INTRODUCTION

The area under consideration comprises approximately 900 square miles in southwestern Puerto Rico. It includes the Yauco area of Slodowski (MS.) and the Mayaguez area of Mattson (MS.), which herein are termed the Mayaguez-Yauco District.

Microfossils were collected during two summers of reconnaissance field work for paleontological and stratigraphic studies. In addition, enough data were compiled to permit paleoecological analyses.

Holotypes of the new species are deposited in the Cole Collection at Cornell University, Ithaca, New York. Paratypes are deposited in the Cole Collection and at the U. S. National Museum, Washington, D. C.

Berkey (1915) broadly grouped the formations of Puerto Rico into two divisions, the Older Series and the Younger Series. The Older Series included rocks that occupy the central and southern portions of the island. More specifically, it included early Tertiary or older rocks that have been folded, faulted and intruded. The Younger Series comprised the gently dipping Oligocene to Recent rocks of the coastal plains. Mattson (MS.) has revised Berkey's divisions to bring them into accordance with modern stratigraphic nomenclature. The following subdivisions are here adopted, after Mattson:

Bermeja complex

Serpentinites, cherts, and amphibolites, typically exposed along the Sierra Bermeja and the west coast at Punta Melones. In southwestern Puerto Rico these are the oldest rocks.

Older Sequence

Deformed unmetamorphosed sediments and igneous rocks of Cretaceous and early Tertiary age. In southwestern Puerto Rico these rocks rest unconformably on the Bermeja complex.

Younger Sequence

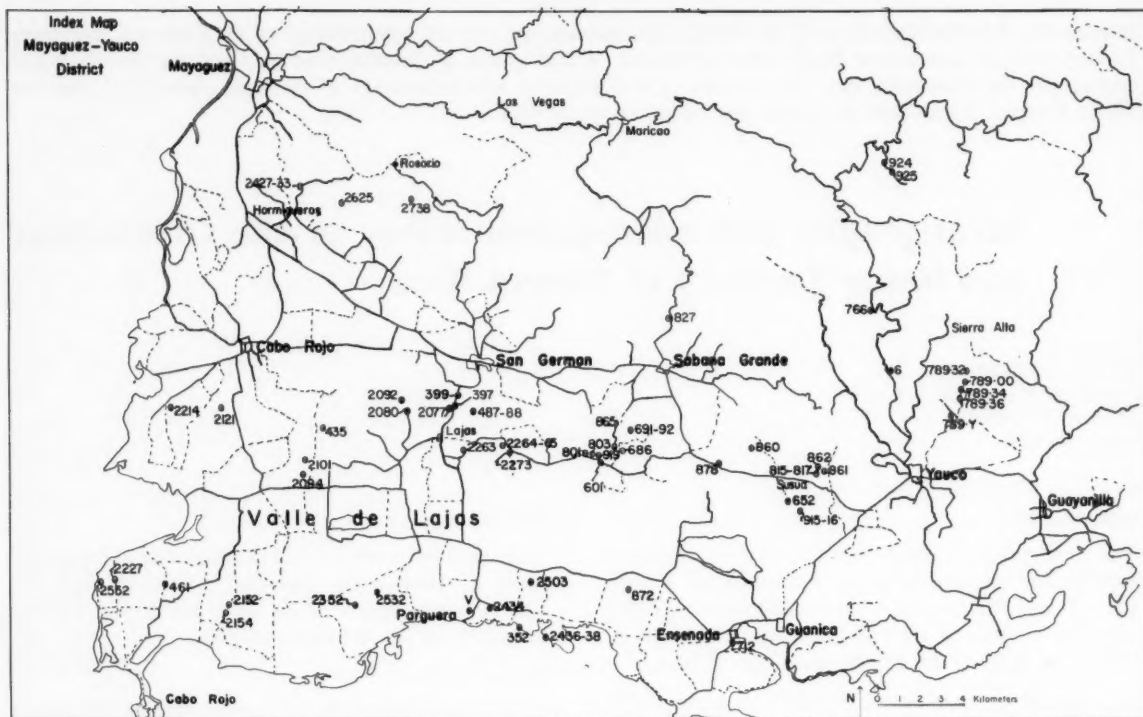
Gently dipping middle Tertiary to Recent sediments of the Coastal Plains. These sediments rest with angular unconformity on the older rocks.

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The field work was financed by the Economic Development Administration of Puerto Rico, and specifically came under the sponsorship of Dr. R. Fernandez Garcia, director of the Chemical Laboratory. Drawings of microfossils were made by Lawrence Isham, of the U. S. National Museum. Dr. G. A. Cooper, of the U. S. National Museum, was instrumental in procuring a grant to pay for the drawings.



TEXT-FIGURE 1
INDEX MAP MAYAGUEZ-YAUCO DISTRICT

BIOSTRATIGRAPHY

The local zonation of the Campanian and Maestrichtian of the Mayaguez-Yauco District is shown in Chart 1. Several criteria are used:

1) *The established ranges of the species of Globotruncana*: These serve as the framework for zonation.

2) *Explosions and evolutionary trends among planktonic foraminifera*: Two marked parallel "explosions" occurred during Campanian and Maestrichtian time; that of *Rugoglobigerina* and that of *Pseudoguembelina*, striate *Heterohelix* (= *Guembelina*), and striate *Pseudotextularia*. These explosions represent a tremendous increase in both number of species and number of individuals. The same "explosions" are observable throughout the Campanian-Maestrichtian sections of the Caribbean region and the Gulf Coast region. Evolutionary trends among the Globotruncanidae are also important (see Systematic Descriptions).

3) *Association and relative abundance of certain planktonics*: The Campanian and Maestrichtian have been divided into range zones, assemblage zones, subzones, and zonules. Range zones are marked by

distinctive species of *Globotruncana*. The *Globotruncana stuarti-formicata-lapparenti* assemblage zone delimits the Campanian to lower Maestrichtian part of the section. Subzones and zonules are established on the basis of the second and third criteria mentioned above. They are named after characteristic species of planktonic foraminifera or radiolaria. A more accurate definition of these zones may be worked out in the future by statistical analysis of the planktonic faunas. Analyses of the "explosions" of *Rugoglobigerina* and *Pseudoguembelina*, striate *Heterohelix*, and striate *Pseudotextularia* on a statistical basis would be particularly rewarding.

Structural complexities due to strong orogenic movements make it difficult to study a given section completely. In spite of such difficulties, representative sections containing the *Globotruncana stuarti-formicata-lapparenti* assemblage zone can be seen in two areas: (1) along the Parguera Range, bordering the coast, and (2) along Quebrada de Quebradas, northeast of Yauco. The section at the Parguera Range includes the *Dictyomitra multcostata-Phacodiscus*(?) sp. zonule at its base and the

MICROPALAEONTOLOGY OF PUERTO RICO

CHART 1

Planktonic Species	Upper Cretaceous											
	Campanian						Maestrichtian					
	Globostruncana fomicata-lapparenti-stuarti assemblage zone						Globostruncana confusa-stuarti assemblage zone					
	subzona	subzona	subzona	subzona	subzona	subzona	subzona	subzona	subzona	subzona	subzona	subzona
A = abundant												
R = rare												
C = common												
--- not observed												
<i>Pseudostrotaria elegans</i>		C	A	A	A	A						
<i>Heterohelix ultimatumida</i>		R	R	R	C	C						
<i>pulchra</i>				R	C	C						
<i>punctulata</i>		R	C	C	A	A						
<i>striata</i>		C	A	A	A	A						
<i>Pseudoglobulina costulata</i>		R	C	A	A	A						
<i>Planoglobulina</i> sp.				R	R							
<i>Gubleria</i> sp.				R	R							
<i>Proaglobotruncana gautierensis</i>		C	C	R								
<i>mattoni</i> n. sp.							C					
<i>Globostruncana</i> (G.) <i>fomicata</i>		A	A	A	A	A						
<i>lapparenti lapparenti</i>		A	A	A	A	A						
<i>lapparenti bufoides</i>		C	C	C	C	C						
<i>lapparenti tricarinata</i>		R	C	C	C	C						
<i>rosetta</i>				C	A	A						
<i>stuarti stuartiformis</i>		A	A	A	A	A						
<i>stuarti elevata</i>						C						
<i>subspinosa</i> n. sp.		R	R	C	C	C						
<i>conica</i>		C	R	C	C	C						
<i>sp. aff. G. arca</i>		R	R	C	C	C						
<i>Globostruncana</i> (G.) <i>flavi</i>					C	A						
<i>gansseri</i>					C	R						
<i>gansseri dicarinata</i> n. subsp.						C						
<i>scotti</i>				R	R	C						
<i>havanensis</i>					C	C						
<i>Phacodiscus</i> sp.		A										
<i>Dicymitra multicastrata</i>		A										
<i>Rugoglobigerina rugosa</i>				C	A	A						
<i>rugosa subrugosa</i>					R	C						
<i>Planammina yaucoensis</i> n. sp.				R	C	C						
Campanian - Maestrichtian												
Zonation												
Mayaguez - Yauco												
District												

Globostruncana lapparenti lapparenti zonule at its top. The *Globostruncana rosetta-Rugoglobigerina rugosa* zonule is not well represented in this section. It occurs at only one locality (Pr. 2434), where the fauna is poorly preserved. Other localities, more or less isolated because of structural complexities, are more representative of this zonule. These localities are chiefly Pr. 2121, Pr. 915, and Pr. 435. The Quebrada de Quebradas section (as studied to date)

includes the *Globostruncana lapparenti lapparenti* zonule at its base and the *Globostruncana gansseri dicarinata* zonule at its top. The fauna contained in the *Globostruncana gansseri dicarinata* zonule is transitional to that of the *Globostruncana gansseri* assemblage zone.

LITHOSTRATIGRAPHY

The oldest rocks exposed in the Mayaguez-Yauco District are those of the Bermeja complex. Serpentinites, amphibolites, and cherts within this complex are definitely pre-Campanian in age. The Bermeja complex is overlain unconformably by the rocks of the Older Sequence. The oldest rocks of the Older Sequence are a series of flows comprising the Rio Loco formation. Relations in the Barranquitas Quadrangle to the east suggest that these flows are Cenomanian or older in age. The Rio Loco formation is overlain disconformably by the Mayaguez group of early Campanian to early Maestrichtian age. Where the Rio Loco is absent, the Mayaguez group may rest directly on the Bermeja complex. In the south the Mayaguez group is overlain with angular unconformity by the San German formation, of early Maestrichtian to (?) Eocene age and the Jicara formation, of late Paleocene to (?) Eocene age. Patches of (?) middle Eocene marls have also been observed in the Lajas Valley area. In the area north of the towns of Hormigueros, San German, and Yauco, the Mayaguez group apparently forms the highest unit. However, southeast of Rosario a small block of the Cotui limestone member of the San German formation rests unconformably on mudstones belonging to the Mayaguez group. Mattson (M.S., p. 117) interprets this limestone as representing a gravity slide block. Chart 3 summarizes the stratigraphy of the Mayaguez-Yauco District. Only the units bearing microfossils are described below.

The Mayaguez group

Parguera limestone: The Parguera limestone was named by Mattson (MS., p. 51). The type area is cited as the range of hills surrounding the fishing village of Parguera. Excellent exposures occur at the sea cliffs east of town. This unit occurs largely in the area south of the towns of Cabo Rojo, San German, and Yauco. It is somewhat over 2000 feet thick at maximum. The Parguera limestone includes thin-bedded black to buff-colored argillaceous limestones with interbedded marls. Glauconite, frequently abundant locally, is disseminated throughout most of the marls and limestones. Limonite is also present, though it may have been introduced later by diagenetic changes in the sediments. Current features are rare to non-existent. Graded bedding was observed in the overturned sequence of the

Parguera Range. The most prominent sedimentary structures appear to be slump structures, both megascopic and microscopic in size. Much of the limestone is colored black by organic material. This coloring is not usually associated with pyrite.

The microfauna of the Parguera limestone is distinctly Tethyan. It is dominated by planktonic species, but 20% to 50% of the fauna may consist of benthonic species. Among the benthonic forms, arenaceous species are prevalent. Few macrofossils are present in the Parguera limestone. Sponges, echinoids, and various trails can be observed in the limestone along the coast at Parguera. Mattson (MS., p. 63) notes *Barrettia monilifera* on Isla Maguey near Parguera.

The Parguera limestone facies was deposited in warm, relatively clear waters of moderate to deep neritic depths, probably between 60 and 100 fathoms. The lack of Miliolidae among the benthonic foraminifera is significant. Norton (1930, p. 339), in his classic study of Recent West Indian faunas, reports that these types have their optimum development between 0 and 50 to 60 fathoms. Other benthonic foraminifera, though common, are never abundant. They rarely constitute 50% of the microfauna. The abundant planktonic species suggest an open-sea circulation, assuring their uniform distribution in all the deposits (Stone, 1956, p. 369). The presence of megafossils such as sponges and echinoids does not necessarily contradict such a picture. The *Barrettia* noted by Mattson on Isla Maguey may have lived on banks of shallower neritic depths, or it may not have been in place.

Chart 2 shows localities, faunal lists, and stratigraphic determinations for the Parguera limestone. Stratigraphic determinations show a range in age from early Campanian (*Dictyomitra multicostata-Phacodiscus*(?) sp. zonule) to early Maestrichtian (*Globotruncana lapparenti lapparenti* zonule). One locality, Pr. 861, contains a reworked fauna whose age can be determined as middle Maestrichtian (*Globotruncana gansseri* assemblage zone).

Rio Yauco mudstone: Mitchell (1922, p. 249) first named the Rio Yauco shale, from exposures along the Rio Yauco. Slodowski (MS., p. 62) redefined the Rio Yauco shale, calling it the Rio Yauco formation in order to include a greater range of lithic types. Mattson (MS., p. 30) includes these rocks as a lithofacies unit of the Mayaguez group. Where typically developed, the Rio Yauco mudstone includes a monotonous sequence of dark-colored pyritic mudstones and siliceous tuff perhaps 9000 feet thick. The bedding varies from thick to thin.

Current features are rare. Slump structures and graded bedding are common. Oscillation ripple marks were observed in one locality. In the area northeast of Yauco (Pr. 789 localities), thin-bedded yellow-brown to gray mudstones alternate with layers of fine chalky marl. The Rio Yauco mudstone is restricted chiefly to the area north of the towns of Cabo Rojo, San German, and Yauco.

The fauna of this lithofacies is distinctly Tethyan. Megafossils are rare. Mollusk fragments are occasionally concentrated in tuffaceous limestones. The microfauna contains a large planktonic component comprising 90% to 100% of the total population. Benthonic foraminifera are usually species of *Dentalina*, *Pseudoglandulina*, and related genera. Dwarf faunas are common in pyritic black shales (Pr. 14, Pr. 924, Pr. 925).

Facies similar to the Rio Yauco mudstone are common in the Caribbean Cretaceous-Lower Tertiary orogenic belt. This monotonous series of mudstones and tuffs was deposited in warm waters of neritic to bathyal depths, probably between 60 and 200 fathoms. The lack of benthonic types points to probably unfavorable bottom conditions. The dwarf faunas in pyritic black mudstones indicate stagnant conditions affecting both bottom and surface waters. Most benthonic species seem to be hardy and adaptable types belonging chiefly to the family Lagenidae. The presence of *Gyroidina* at many localities may be significant, as Norton (1930, pp. 350-351) found that *Gyroidina* has its optimum development at depths below 60 fathoms.

Chart 2 shows localities, faunal lists, and stratigraphic determinations. Available paleontological data demonstrate a stratigraphic range from late Santonian to middle Maestrichtian (base of the *Globotruncana gansseri* assemblage zone).

San German formation

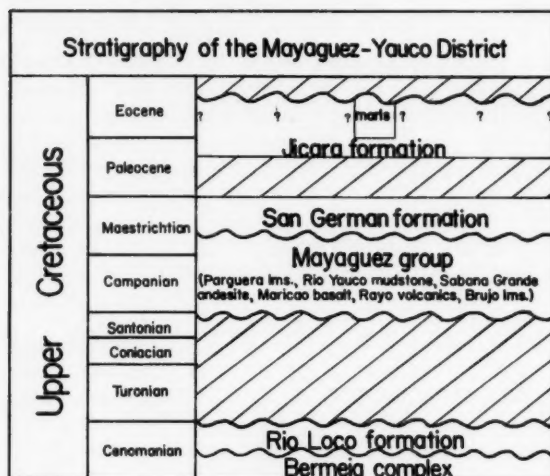
The name San German limestone was first used by Mitchell (1922, p. 253) for massive gray limestone typically exposed in the hills southwest of San German. Inasmuch as erroneous correlations were made by Mitchell, this unit was redefined by Slodowski (MS., pp. 38-86) and by Mattson (MS., p. 102), who included it under the broader designation of San German formation. This formation includes basal volcanics and flows of variable thickness and character, overlain by massive gray limestone. Mattson (MS., p. 107) applied the name Cotui limestone member to the massive limestone. The San German formation is restricted to the foothill belt north of the Lajas Valley. Its maximum thickness is 1800 feet.

MICROPALEONTOLOGY OF PUERTO RICO

CHART 2

Microfossil List		Parquera limestone										Rio Yauco mudstone										Locality																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
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CHART 3
STRATIGRAPHIC RELATIONS (after Mattson)



The Cotui limestone member (0-225 feet) consists mainly of massive light to medium gray limestone whose color varies locally to red, white, and buff. Glauconite and limonite are present, but rarely noticeable megascopically. The limestone contains rounded shell fragments and igneous debris, coralline algae, foraminifera, and varying amounts of argillaceous material. It is usually quite pure.

The fauna of the Cotui limestone contains numerous Tethyan mollusks. Rudistids such as *Barrettia* and *Radiolites* are particularly abundant. Other pelecypods and gastropods, though often abundant locally, are rare as free fossils. *Sulcoperculina*, *Pseudorbitoides*, *Lepidorbitoides*, *Vaughanina*, and *Lockhartia* are common among the larger foraminifera. About 5% or less of the microfauna is planktonic. Among the smaller foraminifera, miliolids are common.

Pure massive gray limestones like the Cotui limestone facies had widespread development in Puerto Rico during late Cretaceous and early Tertiary time. The faunal association of the Cotui limestone facies suggests that the sediments accumulated in warm, clear waters at depths between 0 and 30 fathoms. In such shallow, well aerated waters with strong currents, mollusks often thrived in great numbers. Wave and current action crushed and rounded the shell material, which was then cemented together by calcareous mud.

The initial development of this facies was tectonically controlled. The disturbance which abruptly termi-

nated the deposition of the Parguera limestone in early Maestrichtian time intensely folded the Bermeja complex and its cover of sediments, comprising the Mayaguez group. The irregular outcrop pattern of the Cotui limestone suggests that it accumulated as biostromes on the high points of the submarine terrain resulting from this disturbance.

Chart 2 shows localities, faunal lists, and stratigraphic determinations for the San German formation. Locality Pr. 865 is notable in that it contains an Eocene microfauna. Field relations with the underlying Mayaguez group imply that the lower part of the San German formation is not older than early Maestrichtian (*Globotruncana lapparenti lapparenti* zonule) in age. The Cotui limestone member may be as young as Eocene or as old as early Maestrichtian.

Jicara formation

The Jicara formation was defined originally by Slodowski (MS., p. 92) and was named from Quebrada Jicara, an intermittent stream draining the Lajas Valley. The Jicara formation is best exposed along Route 117 east of Quebrada Jicara and on the road south to Estación La Plata. Outcrops of the Jicara formation are restricted to the eastern end of the Lajas Valley. An erosional inlier, exposed beneath Oligocene-Miocene rocks of the Younger Sequence, occurs in the Bosque Insular de Guanica. The Jicara formation is approximately 3000 feet thick.

Distinctive thin-bedded apple-green siliceous tuffs with a large ash component compose most of the Jicara formation. These beds average about 4 inches thick. Dark red volcanic conglomerate, brown to black calcareous mudstones, and rare massive limestone lenses occur at the base of the formation. The conglomerate, which is 20 feet thick, is heterogeneous and poorly sorted. Massive limestone lenses are lithologically identical to the Cotui limestone member of the San German formation. One such lens, at Pr. 601, lies directly between the basal conglomerate and thin-bedded tuffs.

The fauna of the Jicara formation is sparse, but planktonic foraminifera, chiefly dwarfed *Globigerina* and *Globorotalia*, occur in calcareous mudstones at its base. The apple-green tuffs do not seem to contain foraminifera. The sparse fauna here includes only radiolaria.

The massive limestone lenses at the base of the Jicara formation represent a facies that is quite similar to that of the Cotui limestone. These limestones suggest shallow waters of neritic depth, probably less than

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60 fathoms. The transition from calcareous deposits containing foraminifera to siliceous deposits containing radiolaria suggests an environmental change. Inasmuch as both mudstones and tuffs contain a high percentage of volcanic ash, this environmental change is probably related to ash showers. Ash was mixed with calcareous mud and igneous debris on the sea floor. As it gradually accumulated, the pH of the water changed and eventually became so acid that planktonic foraminifera could not secrete their tests, or possibly their tests dissolved before settling to the bottom. Radiolaria, on the other hand, found the large amount of siliceous material conducive to test secretion. The dwarfing of the pelagic foraminifera in the mudstone-conglomerate facies may indicate a restricted circulation. Stone (1956, p. 369), in his study of planktonic foraminifera in Recent seas, concluded that individuals of the largest sizes occur under the direct influence of ocean currents. If such a restricted circulation existed in the early phases of Jicara deposition, it may be that this area was almost cut off from the sea during the deposition of the green tuff facies.

Chart 2 shows localities, faunal lists, and stratigraphic determinations for the Jicara formation. Two localities at the base of the formation are of late Paleocene age, but a large part of the formation may be Eocene.

Eocene outliers

Outliers of Eocene sediments in the Mayaguez-Yauco District may be of greater significance when more is known about extensive middle Eocene deposits to the east (Ponce, Rio Descalabrado, and Coamo Quadrangles,) which the writer is now investigating. Marls and muddy sandstones contain numerous worn, rounded, and polished shell fragments. Reworked Cretaceous fossils such as corals and rudistids are common. Both the macrofauna and the microfauna are largely benthonic. The faunal assemblage of these rocks suggests littoral zone conditions along an Eocene shoreline.

Chart 2 shows the stratigraphic determinations and faunal lists for these localities. The age of Pr. 2273 and Pr. 801 is based largely on faunal correlation with Pr. 652. Ostracodes and foraminifera at this locality seem to indicate a middle or perhaps early Eocene age. Ostracodes, identified by van den Bold, are as follows: *Cytheridea* spp. A₁, B₁, B₂, C₁, C₂, *Cytherella* sp., *Paracypris* sp., *Brachythere jessupensis*, *Bairdia*. Van den Bold assigns this locality to the lower or middle Eocene (*vide* Bolli, report to H. H. Hess). *Globorotalia densa* was noted at this locality by Bolli.

SYSTEMATIC DESCRIPTIONS

Order FORAMINIFERA

Family LITUOLIDAE

Genus AMMOBACULITES Cushman, 1910

Ammobaculites taylorensis Cushman and Waters

Ammobaculites taylorensis CUSHMAN AND WATERS, 1929, Cushman Lab. Foram. Res., Contr., vol. 5, p. 64, pl. 10, fig. 6a-b. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 23, pl. 3, fig. 21.

Occurrence: Parguera limestone. Gulf Coast: Taylor and equivalents.

Family TEXTULARIIDAE

Genus SPIROPLECTAMMINA Cushman, 1927

Spiroplectammina laevis (Roemer) var. *cretosa* Cushman

Spiroplectammina laevis (Roemer) var. *cretosa* CUSHMAN, 1932, Cushman Lab. Foram. Res., Contr., vol. 8, p. 87, pl. 11, fig. 3a-b. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 27, pl. 6, figs. 1-3.

Occurrence: Parguera limestone. Gulf Coast: Austin-Taylor and equivalents.

Family VERNEUILINIDAE

Genus GAUDRYINA d'Orbigny, 1839

Gaudryina (*Pseudogaudryina*) *pyramidata* Cushman

Gaudryina laevigata Franke var. *pyramidata* CUSHMAN, 1926, Amer. Assoc. Petr. Geol., Bull., vol. 10, p. 587, pl. 16, fig. 8a-b.

Gaudryina (*Pseudogaudryina*) *pyramidata* Cushman. — CUSHMAN, 1937, Cushman Lab. Foram. Res., Spec. Publ. no. 7, p. 87, pl. 12, fig. 13.

Occurrence: Parguera limestone. Upper Cretaceous of Trinidad, Mexico, and California.

Pseudoclavulina sp. cf. *P. clavata* Cushman

Clavulina clavata CUSHMAN, 1925, Amer. Assoc. Petr. Geol., Bull., vol. 10, p. 589, pl. 17, fig. 4.

Pseudoclavulina clavata (Cushman). — CUSHMAN, 1937, Cushman Lab. Foram. Res., Spec. Publ. no. 7, p. 108, pl. 15, figs. 1-13. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, pp. 36-37, pl. 8, figs. 1-2.

Occurrence: Parguera limestone. Upper Cretaceous of the Gulf Coast and Antillean Region.

Genus CLAVULINOIDES Cushman, 1936

Clavulinoides disjunctus (Cushman)

Clavulinoides disjunctus (Cushman). — CUSHMAN, 1931, Cushman Lab. Foram. Res., Spec. Publ. no. 7, p. 125, pl. 18, figs. 1-3.

Clavulinoides disjunctus (Cushman). — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 40, pl. 10, figs. 12-14.

Occurrence: Parguera limestone. Gulf Coast: Taylor and equivalents. Maestrichtian of Sinai (Said and Kenawy, 1956).

Clavulinoides asper (Cushman)

- Clavulina trilatera* Cushman var. *asper* CUSHMAN, 1926, Amer. Assoc. Petrol. Geol., Bull., vol. 10, p. 589, pl. 17, fig. 3.
Clavulina aspera Cushman. – CUSHMAN AND JARVIS, 1932, U. S. Nat. Mus., Proc., vol. 80, art. 114, p. 19, pl. 5, fig. 4.
Clavulinoides aspera (Cushman). – CUSHMAN, 1937, Cushman Lab. Foram. Res., Spec. Publ. no. 7, p. 122, pl. 16, figs. 27–31; pl. 17, figs. 1–3.

Occurrence: Parguera limestone. Common in the Upper Cretaceous of the Caribbean region. Gulf Coast: Austin-Navarro and equivalents. Maestrichtian of Sinai (Said and Kenawy, 1956).

Family VALVULINIDAE

Genus MARSONELLA Cushman, 1933

Marsonella oxycona (Reuss)

- Gaudryina oxycona* REUSS, 1860, K. Akad. Wiss. Wien., Math.-Naturwiss. Kl., Sitzungsber., vol. 40, p. 229, pl. 12, fig. 3.
Marsonella oxycona (Reuss). – CUSHMAN, 1933, Cushman Lab. Foram. Res., Contr., vol. 9, p. 36, pl. 4, fig. 13a–b.

Occurrence: Parguera limestone and Rio Yauco mudstone. This is one of the most common Cretaceous benthonic species in Puerto Rico. It occurs in the Cretaceous throughout the world.

Genus DOROTHIA Plummer, 1931

Dorothia bulleta (Carsey)

- Gaudryina bulleta* CARSEY, 1926, Texas Univ. Bull. no. 2612, pl. 4, fig. 4.
Dorothia bulleta (Carsey). – PLUMMER, 1931, Texas Univ. Bull. no. 3101, p. 132, pl. 8, figs. 13–17. – CUSHMAN, U. S. Geol. Survey, Prof. Paper no. 206, p. 46, pl. 12, figs. 13–17.

Occurrence: Parguera limestone and Rio Yauco mudstone. Common in the Upper Cretaceous of the Caribbean region and the Gulf Coast region (Austin-Navarro).

Dorothia conula (Reuss)

- Textularia conulus* REUSS, 1845, Verstein. böhm. Kreideformation, pt. 1, p. 38, pl. 8, fig. 59.
Dorothia conula (Reuss). – CUSHMAN, 1937, Cushman Lab. Foram. Res., Spec. Publ. no. 8, p. 76, p. 8, figs. 11–17. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, pp. 44–45, pl. 12, figs. 12–14.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of Europe and of the Gulf Coast (Taylor).

Dorothia retusa (Cushman)

- Gaudryina retusa* CUSHMAN, 1926, Amer. Assoc. Petr. Geol., Bull., vol. 10, p. 558, pl. 16, fig. 10a–b.
Dorothia retusa (Cushman). – CUSHMAN, 1937, Cushman Lab. Foram. Res., Spec. Publ. no. 8, p. 85, figs. 33–36. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 46, pl. 13, figs. 1–4.

Occurrence: Parguera limestone and Rio Yauco mudstone. This species is not as common in the Upper Cretaceous of Puerto Rico as either *Dorothia conula* or *Dorothia bulleta*. It is apparently restricted to the Upper Cretaceous of the Caribbean region, and does not occur in the Upper Cretaceous of the Gulf Coast. Said and Kenawy (1956, p. 128) reported it from the Upper Cretaceous of Sinai.

Family LAGENIDAE

Genus ROBULUS Montfort, 1808

Robulus sp. cf. **R. muensteri** (Roemer)

- Robulina muensteri* ROEMER, 1839, Verstein. Norddeutschen Oolithengebirgen, Nachtrag, p. 48, pl. 22, fig. 29.
Robulus muensteri (Roemer). – CUSHMAN, 1932, Jour. Pal., vol. 6, p. 334, pl. 50, fig. 2a–b. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 53, pl. 17, figs. 3–9.

Occurrence: Parguera limestone. Upper Cretaceous of the Gulf Coast and of Europe.

Remarks: Puerto Rican specimens may be referable to this species, as it has great individual variation. They are large (1.7 mm. × 1.5 mm.), but the preservation is poor.

Genus LENTICULINA Lamarck, 1804

Lenticulina sp. cf. **L. nuda** (Roemer)

- Cristellaria nuda* REUSS, 1861, K. Akad. Wiss. Wien., Math.-Naturwiss. Kl., Sitzungsber., vol. 44, pt. 1, pl. 6, figs. 1–3.
Lenticulina nuda (Reuss). – CUSHMAN AND JARVIS, 1928, Cushman Lab. Foram. Res., Contr., vol. 4, p. 96, pl. 14, fig. 2.

Occurrence: Parguera limestone. Gulf Coast: Austin-Navarro. Upper Cretaceous of Sinai.

Remarks: Puerto Rican specimens are comparable to Trinidad specimens in the thickness of their tests. However, the early involute stages seem to be more developed than those of the Trinidad forms.

Lenticulina sp. cf. **L. rotulata** (Lamarck)

- Lenticulina rotulata* (Lamarck). – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, pp. 56–57, pl. 18, fig. 19; pl. 19, figs. 1–7.

Occurrence: Parguera limestone. Gulf Coast: Austin-Navarro. Upper Cretaceous of Sinai.

Genus MARGINULINA d'Orbigny, 1826

Marginulina cretacea Cushman

- Marginulina cretacea* CUSHMAN, 1937, Cushman Lab. Foram. Res., Contr., vol. 13, p. 94, pl. 13, figs. 12–15. – CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 61, pl. 21, figs. 16–20, 39.

Occurrence: Parguera limestone. Gulf Coast: Taylor-Navarro.

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Genus RECTOGLANDULINA Loeblich and Tappan, 1955

Rectoglandulina pygmaea (Reuss)

Glandulina pygmaea REUSS, 1851, Haidinger's Naturwiss. Abh., vol. 4, pt. 1, p. 6, pl. 1, fig. 3.

Pseudoglandulina sp., CUSHMAN AND JARVIS, 1932, U. S. Nat. Mus., Proc., vol. 80, art. 14, p. 37, pl. 11, fig. 13.

Pseudoglandulina pygmaea (Reuss). — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 76, pl. 27, figs. 27–28.

Rectoglandulina pygmaea (Reuss). — LOEBLICH AND TAPPAN, 1955, Smithsonian Misc. Coll., vol. 126, no. 3, pp. 1–9, 1 pl.

Occurrence: Parguera limestone. Gulf Coast: Taylor-Navarro. Upper Cretaceous of the Caribbean region.

Genus DENTALINA d'Orbigny, 1826

Dentalina catenula Reuss

Dentalina catenula REUSS, 1860, K. Akad. Wiss. Wien, Math.-Naturwiss. Kl., Sitzungsber., vol. 40, p. 185, pl. 3, fig. 6. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, pp. 67–68, pl. 23, figs. 27–32.

Occurrence: Rio Yauco formation. Upper Cretaceous of the Gulf Coast, Middle East, and Europe.

Genus NODOSARIA Lamarck, 1816

Nodosaria sp. cf. *N. proboscidea* Reuss

Nodosaria proboscidea REUSS, 1851, Haidinger's Naturwiss. Abh., vol. 4, pt. 1, p. 7, pl. 1, fig. 6. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 72, pl. 26, figs. 12–13.

Occurrence: Parguera limestone. Gulf Coast: Taylor. Upper Cretaceous of Europe.

Genus NEOFLABELLINA Bartenstein, 1949

Neoflabellina interpunctata (von der Marck)

Flabellina interpunctata VON DER MARCK, 1858, Verh. Naturhist. Ver. Preuss. Rheinlands, vol. 15, pl. 1, fig. 5.

Flabellina projecta (Carsey). — PLUMMER, 1931, Texas Univ. Bull. no. 3101, pp. 165–166, pl. 12, figs. 5–8.

Flabellina jarvisi CUSHMAN, 1935, Cushman Lab. For. Res., Contr., vol. 11, p. 85, pl. 13, figs. 7–8.

Neoflabellina interpunctata (von der Marck). — BARTENSTEIN, 1949, Soc. Géol. France, C. R. Somm., no. 9, pp. 164–166.

Occurrence: Parguera limestone. Upper Cretaceous of the Caribbean region, Gulf Coast, Near East, and Europe.

Remarks: This species is characterized by its pustules, raised sutures, and random development of loops.

Family CAMERINIDAE

Genus SULCOPERCULINA Thalmann, 1938

Sulcoperculina dickersoni (Palmer)

Camerina (?) *dickersoni* PALMER, 1934, Soc. Cubana Hist. Nat., Mem., vol. 8, no. 4, pp. 243–245, figs. 1–2, 4, 6, 8.

Sulcoperculina dickersoni (Palmer). — THALMANN, 1938, Eclogae Geol. Helv., vol. 31, p. 330.

Sulcoperculina globosa DE CIZANCOURT, 1949, Soc. Géol. France, Bull., ser. 5, vol. 18, fasc. 8–9, p. 670, pl. 24, figs. 6–7.

Sulcoperculina obesa DE CIZANCOURT, 1949, Soc. Géol. France, Bull., ser. 5, vol. 18, fasc. 8–9, p. 670, pl. 24, figs. 9, 11.

Occurrence: De Cizancourt's species are regarded as variants of *Sulcoperculina dickersoni*, since intergradation occurs between specimens of different height and thickness.

Family HETEROHELICIDAE

Genus PSEUDOTEXTULARIA Rzehak, 1891

Pseudotextularia elegans (Rzehak)

Cuneolina elegans RZEHAK, 1891, Naturhist. Hofmus. Wien, Ann., vol. 6, no. 1, pp. 2, 4.

Guembelina plummerae LOETTERLE, 1937, Nebraska Geol. Survey, Bull., per. 2, no. 12, p. 33, pl. 5, figs. 1–2.

Pseudotextularia elegans (Rzehak). — GALLITELLI, 1957, U. S. Nat. Mus., Bull. no. 215, pt. 1, pp. 138–139, pl. 3, fig. 6.

Occurrence: Parguera limestone and Rio Yauco mudstone. This species occurs in units of Austin to Navarro age in the Gulf Coast section. It is abundant in the Maestrichtian deposits of the Caribbean region. Said and Kenawy (1956, p. 139) noted it in the Maestrichtian deposits of Sinai. Hamilton (1953, p. 234) recorded it from the Upper Cretaceous of the mid-Pacific Guyot area.

Genus HETEROHELIX Ehrenberg, 1841

Heterohelix ultimatumida (White)

Guembelina ultimatumida WHITE, 1929, Jour. Pal., vol. 3, p. 39, pl. 4, fig. 13. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 107, pl. 46, figs. 6–7.

Heterohelix ultimatumida (White). — GALLITELLI, 1957, U. S. Nat. Mus., Bull., no. 215, pp. 137–138.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast, Caribbean region, Near East, and mid-Pacific Guyot area.

Remarks: Puerto Rican specimens show a coiled initial stage. This coiled stage was not observed by Gallitelli (1957, p. 137) in an analysis of fifteen specimens.

Heterohelix pulchra (Brotzen)

Guembelina pulchra BROTZEN, 1936, Sver. Geol. Unders., ser. C, no. 396, p. 121, pl. 9, figs. 2a–b, 3a–b.

Guembelina pseudotessera CUSHMAN, 1938, Cushman Lab. For. Res., Contr., vol. 14, pl. 2, figs. 19–21.

Heterohelix pulchra (Brotzen). — GALLITELLI, 1957, U. S. Nat. Mus., Bull., no. 215, pp. 137–138, pl. 31, fig. 20.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast and Caribbean regions. Mid-Pacific Guyot area.

Remarks: Puerto Rican specimens from Pr. 789.32 show the development of distinct striae. Most specimens show a coiled initial stage.

Heterohelix punctulata (Cushman)

Guembelina punctulata CUSHMAN, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, p. 13, pl. 2, figs. 15-16.

Pseudoguembelina punctulata (Cushman). - BRONNIMANN AND BROWN, 1953, Cushman Found. Foram. Res., Contr., vol. 4, pt. 4, p. 154, text-figs. 7-8.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Caribbean region and Gulf Coast.

Heterohelix striata (Ehrenberg)

Textularia striata EHRENBURG, 1838, K. Preuss. Akad. Wiss. Berlin, Abh. p. 135, pl. 4, figs. 1-3.

Guembelina striata (Ehrenberg). - EGGER, 1899, K. Bayer. Akad. Wiss. München, Math.-Naturh. Abt., Abh., Kl. 2, vol. 21, p. 33, pl. 14, figs. 37-39 (not figs. 10-11).

Pseudoguembelina striata (Ehrenberg). - BRONNIMANN AND BROWN, 1953, Cushman Found. Foram. Res., Contr., vol. 4, pt. 4, p. 154, text-fig. 6.

Occurrence: Parguera limestone and Rio Yauco mudstone. Gulf Coast: Austin-Navarro. Upper Cretaceous of the Caribbean region. The same species has been recorded from the Upper Cretaceous of the Near East and the mid-Pacific Guyot area.

Genus PSEUDOGUEMBELINA Bronnimann and Brown, 1953

Pseudoguembelina costulata (Cushman)

Guembelina costulata CUSHMAN, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, p. 16, pl. 3, figs. 7-9.

Pseudoguembelina costulata (Cushman). - BRONNIMANN AND BROWN, 1953, Cushman Found. Foram. Res., Contr., vol. 4, pt. 4, pp. 153-154.

Occurrence: Parguera limestone and Rio Yauco mudstone. Gulf Coast: Taylor-Navarro. Campanian and Maestrichtian of Israel; Upper Cretaceous of the Near East, Indonesia, and the mid-Pacific Guyot area.

Genus BOLIVINOIDES Cushman, 1927

Bolivinoides decoratus (Jones)

Bolivina decorata JONES, 1886, Belfast Nat. Field Club, Proc., 1884-85, appendix 9, p. 330, pl. 27, figs. 7-8.

Bolivinoides decorata (Jones). - CUSHMAN, 1927, Cushman Lab. Foram. Res., Contr. vol. 2, pt. 4, p. 89, pl. 12, fig. 9. - CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 113, pl. 48, figs. 8-9.

Occurrence: Rio Yauco mudstone. Gulf Coast: Austin-Taylor. Upper Cretaceous of the Caribbean Region.

Family BULIMINIDAE

Genus BULIMINELLA Cushman, 1911

Buliminella lajasensis Pessagno, new species

Plate 2, figures 4-5; plate 4, figures 8-10

External appearance: Test an expanding spiral of three or four whorls; chambers of last whorl somewhat overlap those of the preceding whorl; size of chambers increasing

progressively; coiling left or right; apertural area rimmed by last chamber, which wraps around it in a U-shape; a finger-like projection divides the apertural region into heart- or looped-shaped areas; walls thick, calcareous, perforate; sutures depressed and curved; test about half as wide as high. Diameter of holotype 0.64 mm; height 0.94 mm.

Internal structure: Axial sections (front and lateral views) show chambers revolving around a thick, irregular, tapering, curved axial column; column terminated by a thick, massive arrow-head-like structure (pl. 4, fig. 8); columnar structure with massive terminal portion probably representing the projection separating the apertural area in external view; apertures in axial section lead upward, connecting the chambers between one whorl and the next; apertural flaps parallel to axial column; nepionic chambers round to oval in shape; transverse section of later chambers show gradually expanding chambers of a modified trapezohedral shape; chambers joined by apertures bordering axial column; apertural flaps lead from one chamber to next; flaps wrap around and parallel the axial column (pl. 4, fig. 10).

Type locality: Pr. 2273: 0.2 km. south-southeast of the main road. About 4.8 km. east of Lajas, along Route 117 south of Cerro de Las Cuevas.

Occurrence: Eocene, yellow chalky marl, in an outlier of marl lying unconformably on the Cretaceous Melones limestone.

Remarks: This species is similar to *Buliminella elegantissima* d'Orbigny; it differs from the latter, however, in its curved axis of coiling, its more compressed shape, and its large loop- or heart-shaped apertural area. This form is also closely related to species of *Buliminella* noted by Cushman and Parker (1937, pp. 65-73) from the Eocene of Europe. The species is named for the small town of Lajas, in the Mayaguez-Yauco District of Puerto Rico.

Genus BULIMINA d'Orbigny, 1826

Bulimina sp. cf. *B. kickapooensis* Cole

Bulimina kickapooensis COLE, 1938, Florida, Geol. Survey, Bull. no. 16, p. 45, pl. 3, fig. 5. - CUSHMAN, U. S. Geol. Survey, Prof. Paper no. 206, p. 123, pl. 51, figs. 11-12, 14; pl. 66, fig. 12.

Occurrence: Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast: Austin-Navarro.

Remarks: The Puerto Rican specimen is quite comparable with the Gulf Coast species, but lack of material prevents further study.

Family ELLIPSOIDINIDAE

Genus PLEUROSOTOMELLA Reuss, 1860

Pleurostomella subnodosa Reuss

Pleurostomella subnodosa REUSS, 1860, K. Akad. Wiss. Wien, Math.-Naturwiss. Kl., Sitzungsber., vol. 40, p. 204, pl. 8, fig. 2. - CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 132, pl. 55, figs. 1-9.

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Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast, Caribbean region, Near East, and Europe.

Family ROTALIIDAE Genus GYROIDINA d'Orbigny, 1826

Gyroidina beisseli White

Gyroidina beisseli WHITE, 1928, Jour. Pal., vol. 2, p. 291, pl. 39, fig. 7. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 141, pl. 58, fig. 11.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Caribbean and Gulf Coast regions.

Genus STENSIOINA Brotzen, 1936

Stensioina sp. cf. *S. excolata* (Cushman)

Truncatulina excolata CUSHMAN, 1926, Cushman Lab. Foram. Res., Contr. vol. 2, pt. 1, p. 22, pl. 3, fig. 2a-b.

Stensioina excolata (Cushman). — CUSHMAN AND DORSEY, 1940, Cushman Lab. Foram. Res., Contr., vol. 16, p. 4, pl. 1, fig. 6a-c.

Occurrence: Parguera limestone. Upper Cretaceous of the Gulf Coast and Caribbean region.

Remarks: The Puerto Rican specimens are difficult to differentiate from *Stensioina americana* Cushman and Dorsey (1940, op. cit., p. 5). The latter form may not be a valid species. It probably should be included as a subspecies of *Stensioina excolata*. A more thorough analysis of the internal and external features of these forms is needed.

Genus LOCKHARTIA Davies, 1932

Lockhartia susuaensis Pessagno, new species

Plate 3, figures 8-9; plate 4, figures 1-6

External appearance: Test slightly convex dorsally, often highly convex ventrally. Periphery angular. Chambers average about eighteen in last whorl; holotype with seventeen. Diameter of holotype 1.3 × 1.2 mm.; thickness 0.56 mm. Dorsal surface with large pustules which tend to follow the spiral whorl of chambers; pustules concentrated on initial whorl to form a small boss. Well preserved specimens with a system of grooves; principal grooves located on one or both sides of intercameral septa. Grooves may bifurcate or trifurcate near periphery. Ventral surface with honeycomb network of cavities; grooves lead into network of cavities from the periphery. At periphery, grooves form a complex branching pattern.

Internal structure: Test composed of three to four whorls. Proloculum large and spherical in megalospheric individuals. Chambers about as high as long. Septa straight and rather thick, each with a distinct median line. Vertical section showing an apical angle of 65° for first few whorls; this may increase to about 150° in the last whorl. Umbilical plug with labyrinthic struc-

ture; interconnecting cavities of labyrinth lead into chambers on either side of umbilicus and open at ventral surface by means of pores.

DIMENSIONS IN VERTICAL SECTION

Diameter	Thickness	No. of whorls	Width of umbilical plug at base
1 1.54 mm	0.68 mm	4	0.85 mm
2 1.28 "	0.68 "	3	0.85 "
3 1.06 "	0.56 "	3	0.68 "
4 1.33 "	0.85 "	4	1.02 "

Type Locality: Pr. 801: About 8 km. from Susúa and 6 km. from Lajas.

Occurrence: Muddy sandstone of Paleocene-Eocene age.

Remarks: *Lockhartia susuaensis* differs from *Lockhartia haimi* Davies in being much less convex dorsally and in possessing an angular periphery. The apical angle of *Lockhartia haimi* is much greater than that of *Lockhartia susuaensis*. Furthermore, *Lockhartia susuaensis* possesses no distinct pillars and is of much smaller size than *Lockhartia haimi*. This species is named after the village of Susúa in the Lajas Valley, Puerto Rico.

Genus KATHINA Smout, 1954

Kathina bermudezi (Cole)

Lockhartia bermudezi COLE, 1942, Jour. Pal., vol. 16, no. 5, pp. 640-642, pl. 92, figs. 1-5.

Kathina bermudezi (Cole). — SMOUT, 1954, *Lower Tertiary foraminifera of the Qatar Peninsula*. London: British Museum (Natural History), p. 61, pl. 7, figs. 9-13.

Occurrence: Parguera limestone; Eocene marls and sandstones.

Remarks: *Kathina bermudezi* differs from *Kathina jamaicensis* (Cushman) in being larger and much less convex dorsally, and in having a proportionately larger umbilical plug. Furthermore, *Kathina bermudezi* has more numerous and more massive pillars than does *Kathina jamaicensis*.

Family CHILOSTOMELLIDAE

Genus CHILOSTOMELLOIDES Cushman, 1926

Chilostomelloides tubulosa Pessagno, new species

Plate 2, figure 12-13

Description: Test ovoid to subovoid, often somewhat compressed laterally; wall thick, perforate, smooth. Aperture offset from test in well developed tubular neck; tube with lip around aperture; sutures indistinct. Length 0.8 mm.; breadth 0.6 mm. (lateral view), 0.47 mm. (front view).

Type locality: Pr. 789.32: Approximately 2.75 miles (4.4 km. from Yauco on a dirt road running northeast from Yauco (near city dump) along the Quebrada de Quebradas toward the Sierra Alta.

Occurrence: Rio Yauco mudstone.

Remarks: *Chilostomelloides tubulosa* is similar to *Chilostomelloides oviformis* (Sherborn and Chapman), but it differs from the latter in its well developed tubular apertural neck and in its often rather indistinct sutural pattern.

Genus ALLOMORPHINA Reuss, 1850

Allomorphina sp. cf. *A. trochoides* (Reuss)

Globigerina trochoides REUSS, 1845, Verstein. Böhm. Kreideformation, pt. 1, p. 36, pl. 12, fig. 22.

Allomorphina trochoides (Reuss). — CUSHMAN AND JARVIS, 1932, U. S. Nat. Mus., Proc., vol. 80, art. 14, p. 49, pl. 15, fig. 3a-c. — CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 145, pl. 60, fig. 7.

Occurrence: Parguera limestone. Upper Cretaceous of Europe and the Caribbean region.

Remarks: Lack of material prevents further study.

Family HANTKENINIDAE

Subfamily PLANOMALININAE

Genus PLANOMALINA Loeblich and Tappan, 1946

Planomalina yaucoensis Pessagno, new species

Plate 2, figures 14–15; plate 5, figure 4

External appearance: Test lobulate, biumbilicate, planispirally coiled, with six to eight chambers in last whorl; initial chambers spherical, later chambers ovoid, gradually increasing in size; ornamentation consisting of medium-sized papillae; sutures straight, radial, and depressed; umbilici large and deep; aperture equatorial, a low semicircular opening leading into both umbilical areas from base of last chamber; last chamber frequently compressed or variously distorted. Diameter 0.40 mm.

Internal structure: Uniform planispiral coiling throughout all growth stages; test wall hyaline, perforate; papillae hyaline imperforate; flap-like extensions lead from aperture into umbilical areas.

Type locality: Pr. 789.32: Approximately 2.75 miles (4.4 km.) from Yauco on a dirt road running northeast from Yauco (near city dump) along the Quebrada de Quebradas toward the Sierra Alta.

Occurrence: Parguera limestone and Rio Yauco formation (in chalky marl at the type locality). This species is common in the upper Campanian and lower Maestrichtian of Puerto Rico.

Remarks: This species is somewhat similar to *Planomalina caseyi* (Bolli, Loeblich, and Tappan, 1957). It differs from that form, however, in possessing straight radial sutures and coarse papillae. It also shows a more gradual increase in the size of its chambers than does *Planomalina caseyi*. The species is named for the town of Yauco, near its type locality.

Family ORBULINIDAE

Subfamily GLOBIGERININAE

Genus GLOBIGERINA d'Orbigny, 1826

Globigerina triloculinoides Plummer

Globigerina triloculinoides PLUMMER, 1927, Texas Univ. Bull. no. 2644, pp. 135–136, pl. 8, fig. 10a-c. — BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 143, p. 24, pl. 3, figs. 13–18. — LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, pp. 183–184, pl. 40, fig. 4a-c; pl. 41, fig. 2a-c.

Occurrence: Basal portion of the Jicara formation. Gulf Coast: Midway group. Trinidad: Lizard Springs formation.

Globigerina soldadoensis Bronnimann

Globigerina soldadoensis BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 143, pp. 9–11, pl. 1, figs. 1–9.

Occurrence: Basal portion of the Jicara formation. Lizard Springs, Soldado, and Ramdat formations of Trinidad.

Family GLOBOROTALIIDAE

Genus PRAEGLBOTRUNCANA Bermudez, 1952

Praeglobotruncana gautierensis (Bronnimann)

Globigerina gautierensis BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 140, pp. 11–14, text-fig. 2.

Praeglobotruncana gautierensis (Bronnimann). — BOLLI, 1959, Bull. Amer. Pal., pp. 265–266, pl. 21, figs. 3–6.

Occurrence: Parguera limestone; seldom abundant above the *Dictyomitra multicostata*-*Phacodiscus* (?) sp. zonule. Trinidad: Cenomanian—Senonian.

Praeglobotruncana mattsoni Pessagno, new species

Plate 2, figures 1–3, 6–8

External appearance: Test trochospiral, biconvex to mildly spiroconvex, umbilicate; periphery lobulate; chambers gradually increasing in size, spherical to subovate; last whorl with six or seven chambers; final chamber variously distorted and may be displaced toward umbilicus; holotype showing development of a weak single keel on last chamber; early chambers coarsely spinose; last four or five chambers smooth; sutures depressed, radial, slightly curved on both spiral and umbilical sides. Wall calcareous, finely perforate. Aperture interiomarginal, a very narrow slit, extraumbilical-umbilical in position; large apertural flaps extend into the broad, open umbilicus from each successive chamber.

Internal structure: Test hyaline, finely perforate. Trochospiral coiling throughout; early chambers spherical in cross section; later chambers subovate.

Type locality: Pr. 789: Somewhat less than 2.75 miles (4.4 km.) from Yauco. On a dirt road running north-

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east from Yauco (near city dump) along the Quebrada de Quebradas toward the Sierra Alta.

Occurrence: Rio Yauco mudstone, in chalky marl. This species has been observed only at its type locality.

Remarks: The holotype was chosen chiefly to show the character of the aperture; the aperture in other specimens was obscured by very hard matrix or by larger apertural flaps. The size of the umbilicus and shape of the last chamber are better exemplified by the figured paratype.

This species is somewhat similar to *Praeglobotruncana planispira* (Tappan) in the shape of its chambers and the character of its coiling. Its slit-like aperture, wider umbilicus, and larger apertural flaps clearly distinguish it from *Praeglobotruncana planispira*. The aperture is similar to that of *Praeglobotruncana delirioensis* (Plummer), but is not so high nor open.

The species is named after Dr. P. H. Mattson, in honor of his contribution to the geology of the Mayaguez-Yauco district.

Genus GLOBOROTALIA Cushman, 1927

Globorotalia pseudobulloides (Plummer)

Globigerina pseudobulloides PLUMMER, 1927, Texas Univ. Bull. no. 2644, pp. 133-134, pl. 8, fig. 9a-c.

Globorotalia pseudobulloides (Plummer). — BOLLI, LOEBLICH, AND TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, pp. 40, 73, pl. 17, figs. 19-21; pl. 40, figs. 3a-c, 9a-c.

Occurrence: Basal portion of the Jicara formation. Lizard Springs, Ramdat, and Soldado formations of Trinidad; Midway group of the Gulf Coast and its equivalents on the Atlantic Coast.

Globorotalia acuta Toulmin

Globorotalia wilcoxensis Cushman and Ponton var. *acuta* TOULMIN, 1941, Jour. Pal., vol. 15, p. 608, pl. 82, figs. 6-8.

Globorotalia acuta Toulmin. — LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, pp. 185-186, pl. 47, fig. 5a-c; pl. 55, figs. 4-5; pl. 58, figs. 5a-c.

Occurrence: Basal portion of the Jicara formation. Upper Paleocene of the Gulf Coast, Atlantic Coast, and Caribbean region.

Globorotalia aequa Cushman and Renz

Globorotalia crassata (Cushman) var. *aequa* CUSHMAN AND RENZ, 1942, Cushman Lab. Foram. Res., Contr., vol. 18, p. 12, pl. 3, fig. 3.

Globorotalia aequa Cushman and Renz. — LOEBLICH AND TAPPAN, 1957, U. S. Nat. Mus., Bull. no. 215, p. 186, pl. 46, figs. 7-8; pl. 50, fig. 6a-c.

Occurrence: Base of the Jicara formation. Upper Paleocene of the Gulf Coast, Atlantic Coast, and Caribbean region.

Globorotalia densa (Cushman)

Plate 5, figure 3

Pulvinulina crassata Cushman var. *densa* CUSHMAN, 1925, Amer. Assoc. Petr. Geol., Bull., vol. 9, p. 301.

Globorotalia crassata (Cushman) var. *densa* (Cushman). — CUSHMAN AND BARKSDALE, 1930, Stanford Univ., Contr. Dept. Geol., vol. 1, no. 1, p. 68, pl. 12, fig. 8.

Globorotalia bullbrooki BOLLI, 1957, U. S. Nat. Mus., Bull. no. 215, p. 167, pl. 38, figs. 4-5.

Occurrence: Marls and calcareous tuffs associated with the Cotui limestone (Pr. 865); middle Eocene marls and argillaceous limestones of the Rio Descalabrado Quadrangle (northeast of Juana Diaz).

Remarks: The holotypes of *Globorotalia bullbrooki* Bolli and *Globorotalia densa* (Cushman) were compared and were found to be identical. Thin sections of oriented free specimens show a marked decrease in dorsal flattening from the outer whorl to the nepionic and embryonic whorls. The initial chambers are clearly globigeriniform in shape. The wall is very coarsely perforate.

Globorotalia compressa Plummer

Globorotalia compressa PLUMMER, 1927, Texas Univ. Bull. no. 2644, p. 135, pl. 8, fig. 11.

Occurrence: Basal portion of the Jicara formation. Paleocene of the Gulf and Atlantic Coasts. Paleocene of Cuba and Trinidad.

Family GLOBOTRUNCANIDAE

Genus Rugoglobigerina Bronnimann, 1952

Rugoglobigerina shows many features that are characteristic of both the Orbulinidae and the Globotruncanidae. It has a *Globigerina*-shaped test, an umbilical cover plate with accessory apertures, and the partial development of double keels. *Rugoglobigerina* gave rise directly to many of the Maestrichtian forms of *Globotruncana* (*Rugotruncana*).

Rugoglobigerina rugosa (Plummer)

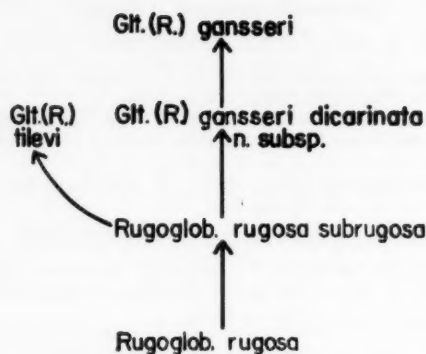
Globigerina rugosa PLUMMER, 1927, Texas Univ. Bull. no. 2644, pp. 38-39, pl. 2, fig. 10a-c.

Rugoglobigerina rugosa (Plummer). — BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 143, pp. 28-33, text-figs. 11-13.

Rugoglobigerina macrocephala BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 143, pp. 25-27, text-figs. 9-10, pl. 2, figs. 1-3.

Occurrence: Parguera limestone, Rio Yauco, and San German formations. *Rugoglobigerina rugosa* is a prominent species in the Maestrichtian deposits of the Caribbean and Gulf Coast regions. It has been observed as far north as New Jersey.

Remarks: The subspecies *Rugoglobigerina rugosa rugosa* and *Rugoglobigerina rugosa pennyi* (see Bronnimann, 1952) are not differentiated in this paper. Gandolfi (1955) elevated *Rugoglobigerina pennyi* to specific rank.



TEXT-FIGURE 2

Rugoglobigerina rugosa subrugosa (Gandolfi)

Globotruncana (Rugoglobigerina) rugosa subrugosa GANDOLFI, 1955
Bull. Amer. Pal., vol. 36, no. 155, p. 73, pl. 7, fig. 5a-c.

Occurrence: Rio Yauco mudstone, chiefly in the *Globotruncana (R.) gansseri dicarinata* zone.

Remarks: This variant of *Rugoglobigerina rugosa* (Plummer) is unique in its development of a faint to well developed double keel structure. Rugosities became oriented to form keels or bands. Frequently, the keel structures occur on all but the last chambers of adult specimens.

Rugoglobigerina rugosa subrugosa (Gandolfi) is associated in the same fauna with *Globotruncana (Rugotruncana) tilevi* Bronnimann and Brown, *Globotruncana (Rugotruncana) gansseri dicarinata* n. subsp., and *Globotruncana (Rugotruncana) gansseri* Bolli. All of these forms show a double-keeled rugoglobigerine nepionic stage in thin sections of oriented free specimens. The fauna shows all stages of development between the mutant *Rugoglobigerina rugosa subrugosa* and *Globotruncana (Rugotruncana) tilevi* and *Globotruncana (Rugotruncana) gansseri dicarinata*. *Globotruncana (Rugotruncana) gansseri* was derived gradationally from *Globotruncana (Rugotruncana) gansseri dicarinata*. The relationship between these forms is shown in text-figure 2. *Rugoglobigerina rugosa subrugosa* gave rise to *Globotruncana (Rugotruncana) tilevi* by vertical compression of its spherical chambers and mild dorsal flattening of the test. It gave rise to *Globotruncana (Rugotruncana) gansseri dicarinata* by extreme dorsal flattening and the migration of the double-keel band to the dorsal periphery.

Genus **GLOBOTRUNCANA** Cushman, 1927

Subgenus **Globotruncana** Cushman, 1927

Globotruncana s. s. includes those forms having a nonrugose globigeriniform nepionic stage in thin sections of oriented free specimens. It is suggested that the ancestral form of *Globotruncana* s. s. was a nonrugose equivalent of *Rugoglobigerina rugosa* (Plummer). It is probable that such a nonrugose ancestor will be found to possess an

umbilical cover plate, tegillae, and other features possessed by *Rugoglobigerina*. *Globotruncana (Globotruncana) saratogaensis* (Applin), as described by Bronnimann and Brown (1956, p. 544), is probably very close to this postulated ancestor except that it possesses a weak double-keel structure.

Globotruncana (Globotruncana) lapparenti lapparenti
Brotzen

Globotruncana lapparenti Brotzen *lapparenti* Brotzen. - BOLLI, 1944, *Eclogae Geol. Helv.*, vol. 37, no. 2, p. 230, text-fig. 1 (15-16) pl. 9, fig. 11.

Globotruncana canaliculata (Reuss). - CUSHMAN, 1946 (part), U. S. Geol. Survey, Prof. Paper no. 206, p. 149, pl. 61, fig. 17a-c.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast: Austin-Navarro. Upper Cretaceous (Senonian-Lower Maestrichtian) in the Tethyan faunal province.

Globotruncana (Globotruncana) lapparenti bulloides
(Vogler)

Globotruncana linnei (d'Orbigny) subsp. *bulloides* VOGLER, 1941, *Paleontographica*, Supplement, vol. 4, pl. 23, figs. 32-39.

Globotruncana lapparenti Brotzen subsp. *bulloides* Vogler. - BOLLI, 1944, *Eclogae Geol. Helv.*, vol. 37, no. 2, pp. 231-232, text-fig. 1 (17-18), pl. 9, fig. 12.

Globotruncana marginata (Reuss). - CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 150, pl. 62, fig. 17a-c.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast: Austin-Navarro. Upper Cretaceous (Senonian-lower Maestrichtian) in the Tethyan faunal province.

Globotruncana (Globotruncana) lapparenti tricarinata
(Quereau)

Pulvinulina tricarinata QUEREAU, 1893, *Beitr. Geol. Karte Schweiz*, no. 33, pl. 5, fig. 3a.

Globotruncana lapparenti tricarinata (Quereau). - BOLLI, 1944, *Eclogae Geol. Helv.*, vol. 37, no. 2, pp. 232-233, text-fig. 1 (19-20), pl. 9, fig. 13.

Globotruncana canaliculata (Reuss). - CUSHMAN, 1946 (part), U. S. Geol. Survey, Prof. Paper no. 206, p. 149, pl. 61, fig. 18a-c.

Occurrence: Parguera limestone and Rio Yauco formation. Upper Cretaceous of the Gulf Coast. Senonian to lower Maestrichtian in the Tethyan faunal province.

Globotruncana (Globotruncana) rosetta (Carsey)
Plate 3, figures 4-7; plate 5, figures 6, 9

Globigerina rosetta CARSEY, 1926, *Texas Univ. Bull.* no. 2612, p. 44, pl. 5, fig. 3a-c.

Globotruncana arca (Cushman). - PLUMMER, 1931, *Texas Univ. Bull.* no. 3101, p. 195, pl. 13, figs. 9a-c, 11a-c.

Globotruncana rosetta (Carsey). - BRONNIMANN AND BROWN, 1955, *Eclogae Geol. Helv.*, vol. 48, p. 545, pl. 21, figs. 11-13.

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External appearance: Test planoconvex; convexity of ventral side highly variable; dorsal side flat to mildly convex, with straight to slightly curved beaded sutures; five or six chambers in the final whorl of mature specimens; last chamber often displaced toward ventral side; narrow double keel following dorsal periphery and merging to form a sharp single keel, usually on the final chamber of adult specimens; test highly lobulate in adult; immature specimens with somewhat wider double keels on all chambers.

Internal structure: Thin sections of oriented free specimens show a double-keeled nepionic stage with a definite affinity to *Globotruncana (Globotruncana) lapparenti tricarinata* (Quereau); distinctive rim-like thickening along the umbilical margin of the last chamber of the nepionic whorl; thickness (height) of double keel in nepionic individual greater than that in adult individual (0.0768–0.032 mm.; 0.096–0.064 mm. in two specimens measured).

Occurrence: Parguera limestone and Rio Yauco mudstone. This species is common in the upper Campanian and lower Maestrichtian of Puerto Rico. Gulf Coast: Taylor-Navarro. Caribbean region: Campanian-Maestrichtian. Upper Cretaceous of California.

Remarks: This species shows a tendency to lose its double keel structure in the adult stage. *Globotruncana (Globotruncana) rosetta* has been misidentified more than any other species of *Globotruncana*. Poorly preserved specimens are difficult to differentiate externally from *Globotruncana (Globotruncana) stuarti* and *Globotruncana (Rugotruncana?) gagnebini*. In thin section, its characteristic double-keeled nepionic stage distinguishes it clearly from those species.

Globotruncana (Globotruncana) fornicata Plummer Plate 4, figure 7

Globotruncana fornicata PLUMMER, 1931, Texas Univ. Bull. no. 3101, p. 198, pl. 13, figs. 4a–c, 5–6.

Occurrence: Parguera limestone and Rio Yauco mudstone.

Remarks: This is undoubtedly one of the most distinctive species of *Globotruncana* s.s. Its biconvex test, its lenticular, crenulated dorsal chambers, and its ventrally inturned double keel are diagnostic.

Globotruncana (Globotruncana) stuarti stuartiformis Dalbiez Plate 5, figures 7, 11

Globotruncana (Globotruncana) elevata stuartiformis DALBIEZ, 1955, Micropaleontology, vol. 1, no. 2, p. 169, text-fig. 10a–c.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast. Campanian-Maestrichtian of the Tethyan faunal province.

Remarks: This form, together with *Globotruncana (Globotruncana) stuarti* (de Lapparent) s.s. and *Globotruncana*

(*Globotruncana*) *stuarti elevata*, is included in the *Globotruncana stuarti* group. All of these forms are distinctly single-keeled in all growth stages except the embryonic stage.

Globotruncana (Globotruncana) stuarti elevata (Brotzen)

Plate 5, figures 1, 8

Rotalia elevata BROTZEN, 1934, Deutsch. Ver. Palästinas, Zeitschr., vol. 57, p. 66, pl. 3, fig. c.

Globotruncana (Globotruncana) elevata elevata (Brotzen). – DALBIEZ, 1955, Micropaleontology, vol. 1, no. 2, p. 169, text-fig. 9a–c.

Occurrence: Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast. Campanian and Maestrichtian of the Tethyan faunal province.

Remarks: *Globotruncana (Globotruncana) stuarti elevata* differs externally from *Globotruncana (Globotruncana) stuarti stuartiformis* in its highly convex ventral side and more lobulate periphery, although there is considerable variation in the arrangement of the chambers. The sutures vary from straight to curved. The raised central cone is not as prominent in Puerto Rican specimens. Internally, *Globotruncana (Globotruncana) stuarti elevata* and *Globotruncana (Globotruncana) stuarti stuartiformis* exhibit similar nepionic and embryonic stages. The wall structure of *Globotruncana stuarti elevata* is strikingly different from that of *Globotruncana stuarti stuartiformis*, as *Globotruncana stuarti elevata* shows coarsely perforate walls and massive, knob-like structures connecting wall partitions.

It is often difficult to differentiate immature specimens of *Globotruncana (Globotruncana) stuarti elevata* from *Globotruncana (Rugotruncana) gansseri* Bolli externally, although the former has a much larger umbilical area and is less convex ventrally. Oriented thin sections show the differences (compare pl. 4, fig. 11, and pl. 5, figs. 1, 8).

Globotruncana (Globotruncana) subspinoso Pessagno, new species

Plate 1, figures 1–9; plate 5, figure 5

External features: Test trochospirally coiled, biconvex to moderately convex ventrally and slightly convex dorsally. Umbilicus large, often flanked by a beaded margin. Sutures straight to slightly curved dorsally, moderately curved ventrally, usually heavily beaded. Chambers more or less angular rhombohedral in shape; six to seven chambers in last whorl; dorsal surface of chambers sometimes crenulate. Periphery single-keeled, usually quite lobulate. Wall calcareous, finely perforate. Primary aperture interiomarginal, umbilical.

Internal structure: Early chambers “globigeriniform” or spherical in cross section. Later chambers becoming

angular rhombohedral in shape and developing a pinched-out single keel often resembling a spine in thin section. Wall radial, hyaline, finely perforate.

Type locality: Pr. 789.Y: approximately 1.9 miles (2.95 km.) from Yauco, along a dirt road running northeast from Yauco (near city dump) along the Quebrada de Quebradas toward the Sierra Alta; in chalky marl.

Occurrence: Parguera limestone and Rio Yauco mudstone; *Dictyomitra multicostata*-*Phacodiscus* (?) sp. zonule to *Globotruncana* (*Globotruncana*) *lapparenti* *lapparenti* zonule.

Remarks: This species is related to the *Globotruncana stuarti* group. More particularly, it seems to be related to *Globotruncana stuarti stuartiformis* (Dalbiez). The wall structures of both of these forms are quite similar (compare pl. 5, fig. 11). *Globotruncana subspinosus* differs from *Globotruncana stuarti stuartiformis* in its development of a pinched-out single keel resembling a spine in thin section, in its extremely lobulate periphery, and in the crenulate nature of its chambers. It differs markedly from *Globotruncana stuarti elevata* (Brotzen) in its wall structure (compare pl. 5, figs. 1,8), in its less convex ventral side, and in its pinched-out single keel. *Globotruncana subspinosus* might possibly be confused with *Globotruncana* (*Rugotruncana*?) *calcarata* Cushman. However, the holotype of *Globotruncana* (*Rugotruncana*?) *calcarata* shows hemispherical chambers and well developed spines.

Paratypes (pl. 1, figs. 1-3, 7-9) show the maximum amount of variation found in the species population. These variants are not as common since most individuals resemble the holotype. The thin-sectioned paratype was almost identical with the holotype in external features.

***Globotruncana* (*Globotruncana*) *conica* White**

Globotruncana conica WHITE, 1928, Jour. Pal. 2, p. 280, pl. 38, fig. 7a-c.

Globotruncana conica White. - CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 151, pl. 61, fig. 20a-c.

Occurrence: Parguera limestone and Rio Yauco mudstone. Upper Cretaceous of the Gulf Coast. Campanian-Maestrichtian of the Tethyan faunal province.

Remarks: Puerto Rican specimens often show evidence of a double-keel structure on the early chambers of the last whorl. The double keel gives way to a single keel on the following chambers. This double-keel stage is not always perceptible in a study of external features alone. Thin sections of oriented free specimens from both the Gulf Coast and Puerto Rico were found to show this double keel in the early growth stages. *Globotruncana conica* is probably related to *Globotruncana lapparenti* Brotzen or *Globotruncana fornicata* Plummer. It cannot be related to the *Globotruncana stuarti* group as has been suggested by Bolli (1951, p. 196) and various other workers.

***Globotruncana* (*Globotruncana*) sp. aff. *G.* (*G.*) *arca* (Cushman)**

Pulvinulina arca CUSHMAN, 1926, Cushman Lab. Foram. Res., Contr., vol. 2, p. 23, pl. 3, fig. 1a-c.

Globotruncana arca (Cushman). - CUSHMAN, 1946 (part), U. S. Geol. Survey, Prof. Paper no. 206, p. 150, pl. 62, fig. 4a-c (not fig. 5a-c).

Occurrence: Parguera limestone and Rio Yauco mudstone. Navarro of the Gulf Coast. Campanian and Maestrichtian of the Caribbean region and the Near East.

Subgenus *Rugotruncana* Bronnimann and Brown, 1956

Rugotruncana Bronnimann and Brown (1956) is emended somewhat to include all forms showing a rugose nepionic stage in thin sections of oriented free specimens. *Rugotruncana* was derived from *Rugoglobigerina*, whereas *Globotruncana* s.s. was derived from a related genus (as yet unnamed in free specimens) lacking rugosities. Phylogeny is here regarded as a more important criterion in classification than a myriad of morphological differences.

***Globotruncana* (*Rugotruncana*) *tilevi* (Bronnimann and Brown)**

Plate 5, figure 10

Rugotruncana tilevi BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48 (1955), no. 2, pp. 547-548, pl. 22, figs. 1-3.

Occurrence: Rio Yauco mudstone. Maestrichtian of Cuba. Lower Maestrichtian of Puerto Rico.

Remarks: *Globotruncana* (*Rugotruncana*) *tilevi* is associated with *Rugoglobigerina rugosa subrugosa* (Gandolfi) and intergrades with it. Oriented sections show a rugoglobigerine nepionic stage with a double keel. *Globotruncana* (*Rugotruncana*) *ellisi* (Bronnimann and Brown) should probably be included in the synonymy of this species.

***Globotruncana* (*Rugotruncana*) *gansseri* (Bolli)**

Plate 4, figure 11

Globotruncana gansseri BOLLI, 1951, Jour. Pal., vol. 25, p. 196, pl. 35, figs. 1-3.

Rugotruncana gansseri (Bolli). - BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48 (1955), no. 2, pp. 549-550, pl. 23, figs. 7-9; text-fig. 23.

Occurrence: Parguera limestone and Rio Yauco mudstone. Middle Maestrichtian and early upper Maestrichtian in the Tethyan faunal province. This species is common in the upper part of the Navarro group (Corsicana marl - Kemp clay and their equivalents).

Remarks: Thin sections frequently show a double-keeled rugoglobigerine nepionic stage, but some individuals may lack this stage. It is possible that the rugoglobigerine stage is present only in microspheric individuals.

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Globotruncana (Rugotruncana) gansseri dicarinata Pessagno, new subspecies

Plate 2, figures 9-11; plate 3, figures 1-3; plate 5, figure 2

External features: Test trochospirally coiled; dorsal side flat to mildly convex; ventral side highly convex. Umbilicus small. Chambers hemispherical in shape; five chambers in the last whorl. Coarse rugosities cover the early chambers and the first two or three chambers of the last whorl; rugosities often with a meridional pattern ventrally. Double-keel band along dorsal periphery, merging to form a single keel in chambers of last whorl; immature specimens usually with double keel throughout, sometimes with single keel on last chambers. Primary aperture interiomarginal, umbilical. Wall calcareous, finely perforate.

Internal structure: Rugoglobigerine nepionic stage with distinct double-keel structure. Wall radial, hyaline, perforate; rugosities and keel structures imperforate.

Type locality: Pr. 789.32: Approximately 2.75 miles (4.4 km.) from Yauco, along a dirt road running north-east from Yauco (near city dump) along the Quebrada de Quebradas toward the Sierra Alta; in chalky marl.

Occurrence: Rio Yauco mudstone.

Remarks: This subspecies differs from *Globotruncana (Rugotruncana) gansseri* (Bolli) in possessing a distinct double-keel band along the dorsal periphery and in the presence of well developed rugosities in the early stages. *Globotruncana (Rugotruncana) gansseri dicarinata* is intermediate between *Rugoglobigerina rugosa subrugosa* (Gandolfi) and *Globotruncana (Rugotruncana) gansseri* (Bolli). It evolved from *Rugoglobigerina rugosa subrugosa* by dorsal flattening and the migration of the double-keel band to the dorsal periphery.

Globotruncana (Rugatruncana) scotti (Bronnimann)

Trinitella scotti BRONNIMANN, 1952, Bull. Amer. Pal., vol. 34, no. 140, pp. 56-58, pl. 4, figs. 4-6; text-fig. 30.

Occurrence: Parguera limestone and Rio Yauco mudstone. Very abundant in the middle and upper Maestrichtian of the Caribbean region. Maestrichtian of the Gulf Coast.

Globotruncana (Rugotruncana) havanensis Voorwijk

Globotruncana havanensis VOORWIJK, 1937, K. Akad. Wetensch. Amsterdam, Proc., Sect. Sci., vol. 40, p. 195, pl. 1, figs. 25-26, 29.

Globotruncana citae BOLLI, 1951, Jour. Pal., vol. 25, p. 197, pl. 35, figs. 4-6.

Rugotruncana havanensis (Voorwijk). - BRONNIMANN AND BROWN, 1956, Eclogae Geol. Helv., vol. 48 (1955), no. 2, p. 552, pl. 17, figs. 4-6; pl. 24, figs. 5 (part), 10.

Occurrence: Rio Yauco mudstone. This is a common species in the Maestrichtian of the Caribbean region. It is also known from the Gulf Coast region and the Near East.

Remarks: Puerto Rican specimens from Pr. 789.32 show coarse rugosities on the early chambers, but the later chambers are finely hispid.

Family ORBITOIDIDAE

Genus PSEUDORBITOIDES H. Douvillé, 1922

Pseudorbitoides israelskii Vaughan and Cole

Pseudorbitoides israelskii VAUGHAN AND COLE, 1932 (part), Nat. Acad. Sci., Proc., vol. 18, no. 10, p. 614, pl. 2, all figs. - VAUGHAN AND COLE, 1943, Jour. Pal., vol. 17, no. 1, p. 98, pl. 17, figs. 1-2.

Occurrence: Parguera limestone.

Family ANOMALINIDAE

Genus PLANULINA d'Orbigny, 1826

Planulina taylorensis (Carsey)

Anomalina taylorensis CARSEY, 1926, Texas Univ. Bull. no. 2612, p. 47, pl. 6, fig. 1a-b.

Planulina taylorensis (Carsey). - CUSHMAN, 1931, Tenn. Div. Geol., Bull. no. 41, p. 62, pl. 12, fig. 5a-c.

Planulina texana CUSHMAN, 1938, Cushman Lab. Foram. Res., Contr., vol. 14, p. 69, pl. 12, fig. 3a-c.

Test trochoid, evolute, with later chambers becoming lobulate; young forms sharply keeled, with no lobulation.

Occurrence: Parguera limestone and Rio Yauco mudstone. Gulf Coast: Austin-Navarro. Upper Cretaceous of the Caribbean region.

Remarks: *Planulina texana* represents little more than the youthful stage of *Planulina taylorensis*.

Genus CIBICIDES Montfort, 1808

Cibicides sp. cf. **C. subcarinatus** Cushman and Deaderick

Cibicides subcarinatus CUSHMAN AND DEADERICK, 1944, Jour. Pal., vol. 18, p. 341. - CUSHMAN, 1946, U. S. Geol. Survey, Prof. Paper no. 206, p. 159, pl. 65, figs. 8-11.

Occurrence: Parguera limestone and Rio Yauco mudstone. Gulf Coast: Taylor-Navarro.

Order RADIOLARIA

Family STRICHOCORYTHIDAE

Genus DICTYOMITRA Zittel, 1876

Dictyomitra multicostata Zittel

Dictyomitra multicostata ZITTEL, 1876, Zeitschr. Deutsch. Geol. Ges., vol. 28, p. 81, pl. 2, figs. 2-4. - CAMPBELL and CLARK, 1944, Geol. Soc. Amer., Spec. Paper no. 57, pp. 39-40, pl. 8, figs. 22-24, 29, 35, 42. - NAUSS, 1947, Jour. Pal., vol. 21, p. 341, pl. 48, figs. 3, 8. - BOLIN, 1956, Jour. Pal., vol. 30, pp. 295-296, pl. 39, fig. 19.

Occurrence: Parguera limestone. Upper Santonian and lower Campanian of Puerto Rico. Upper Cretaceous of Canada, California, and Minnesota. In the lowermost

Campanian of Puerto Rico it is commonly associated with a distinctive species of *Phacodiscus*(?) (unnamed). This species of *Phacodiscus*(?) is characterized by its ornamentation, which consists of triangularly shaped areas bounded by raised partitions; triangles have distinct pustules at their vertices.

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EXPLANATION OF PLATES

PLATE 1

- 1-3 *Globotruncana (Glt.) subspinoso* Pessagno, n. sp.
Paratype; dorsal, ventral, and peripheral views;
× 80.
- 4-6 *Globotruncana (Glt.) subspinoso* Pessagno, n. sp.
Holotype; dorsal, ventral, and peripheral views;
× 80.
- 7-9 *Globotruncana (Glt.) subspinoso* Pessagno, n. sp.
Paratype; dorsal, ventral, and peripheral views;
× 80.

PLATE 2

- 1-3 *Praeglobotruncana mattsoni* Pessagno, n. sp.
Holotype; dorsal, ventral, and peripheral views;
× 80.
- 4-5 *Buliminella lajasensis* Pessagno, n. sp.
Holotype; side and front views; × 40.
- 6-8 *Praeglobotruncana mattsoni* Pessagno, n. sp.
Paratype; dorsal, ventral, and peripheral views;
× 80.
- 9-11 *Globotruncana (R.) gansseri dicarinata* Pessagno,
n. subsp.
Holotype; dorsal ventral, and peripheral views;
drawing showing matrix-filled crack in last
chamber; × 80.
- 12-13 *Chilostomelloides tubulosa* Pessagno, n. sp.
Holotype; side and front views; × 40.
- 14-15 *Planomalina yaucoensis* Pessagno, n. sp.
Holotype; peripheral and side views; × 80.

PLATE 3

- 1-3 *Globotruncana (R.) gansseri dicarinata* Pessagno,
n. subsp.
Paratype; dorsal, peripheral, and ventral views;
× 80.
- 4-7 *Globotruncana (Globotruncana) rosetta* (Carsey)
Peripheral, dorsal, ventral, and peripheral views;
× 65.
- 8-9 *Lockhartia susuaensis* Pessagno, n. sp.
Holotype; dorsal and ventral views; × 46.

PLATE 4

(Sectioned matrix-free specimens)

- 1 *Lockhartia susuaensis* Pessagno, n. sp.
Paratype; vertical section; × 30.
- 2 *Lockhartia susuaensis* Pessagno, n. sp.
Paratype; vertical section; gerontic individual;
× 30.

- 3-4 *Lockhartia susuaensis* Pessagno, n. sp.
Paratypes; horizontal sections cut close to ven-
tral surface; note umbilical cavities opening into
grooves or canals leading to periphery; × 30.
- 5 *Lockhartia susuaensis* Pessagno, n. sp.
Paratype; horizontal section not quite cutting
proloculum; × 30.
- 6 *Lockhartia susuaensis* Pessagno, n. sp.
Paratype; horizontal section; × 30.
- 7 *Globotruncana (Glt.) fornicata* Plummer
Vertical section; crossed nicols; × 50.
- 8-10 *Buliminella lajasensis* Pessagno, n. sp.
Paratype; axial-front, axial-lateral, and trans-
verse sections; × 50.
- 11 *Globotruncana (R.) gansseri* Bolli
Vertical section; crossed nicols; × 50.

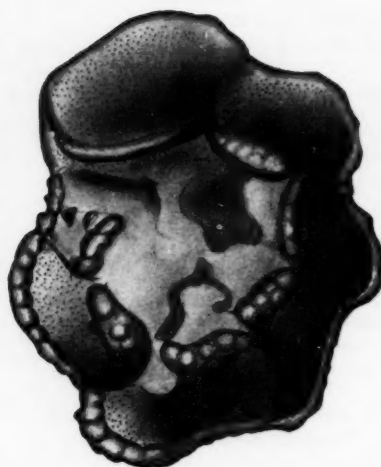
PLATE 5

(Sectioned matrix-free specimens)

- 1 *Globotruncana (Glt.) stuarti elevata* (Brotzen)
Vertical section; × 200.
- 2 *Globotruncana (R.) gansseri dicarinata* Pessagno,
n. subsp.
Paratype; vertical section; crossed nicols; × 50.
- 3 *Globorotalia densa* (Cushman)
Vertical section; crossed nicols; × 50.
- 4 *Planomalina yaucoensis* Pessagno, n. sp.
Paratype; vertical section; crossed nicols; × 50.
- 5 *Globotruncana (Glt.) subspinoso* Pessagno, n. sp.
Paratype; vertical section; × 200.
- 6 *Globotruncana (Glt.) rosetta* (Carsey)
Vertical section; × 50.
- 7 *Globotruncana (Glt.) stuarti stuartiformis* (Dalbiez)
Vertical section showing sharp single keel;
× 200.
- 8 *Globotruncana (Glt.) stuarti elevata* (Brotzen)
Vertical section; crossed nicols; × 50.
- 9 *Globotruncana (Glt.) rosetta* (Carsey)
Vertical section; × 50.
- 10 *Globotruncana (R.) tilevi* Bronnimann and Brown
Vertical section; crossed nicols; × 50.
- 11 *Globotruncana (Glt.) stuarti stuartiformis* (Dalbiez)
Vertical section; × 200.



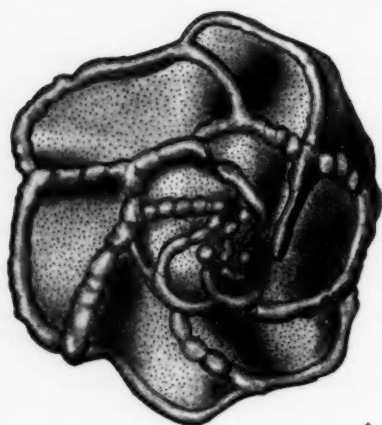
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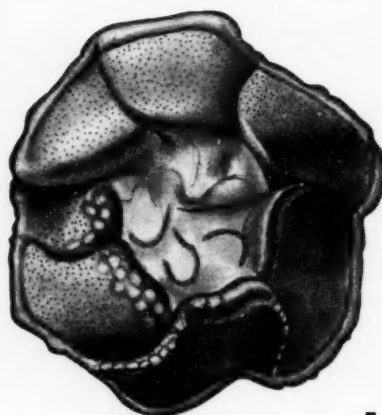
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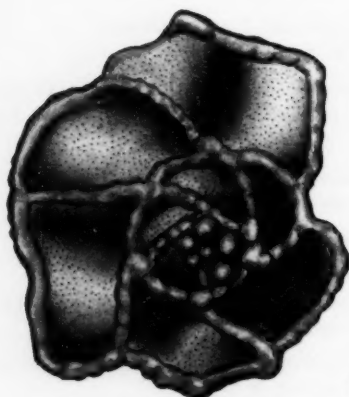
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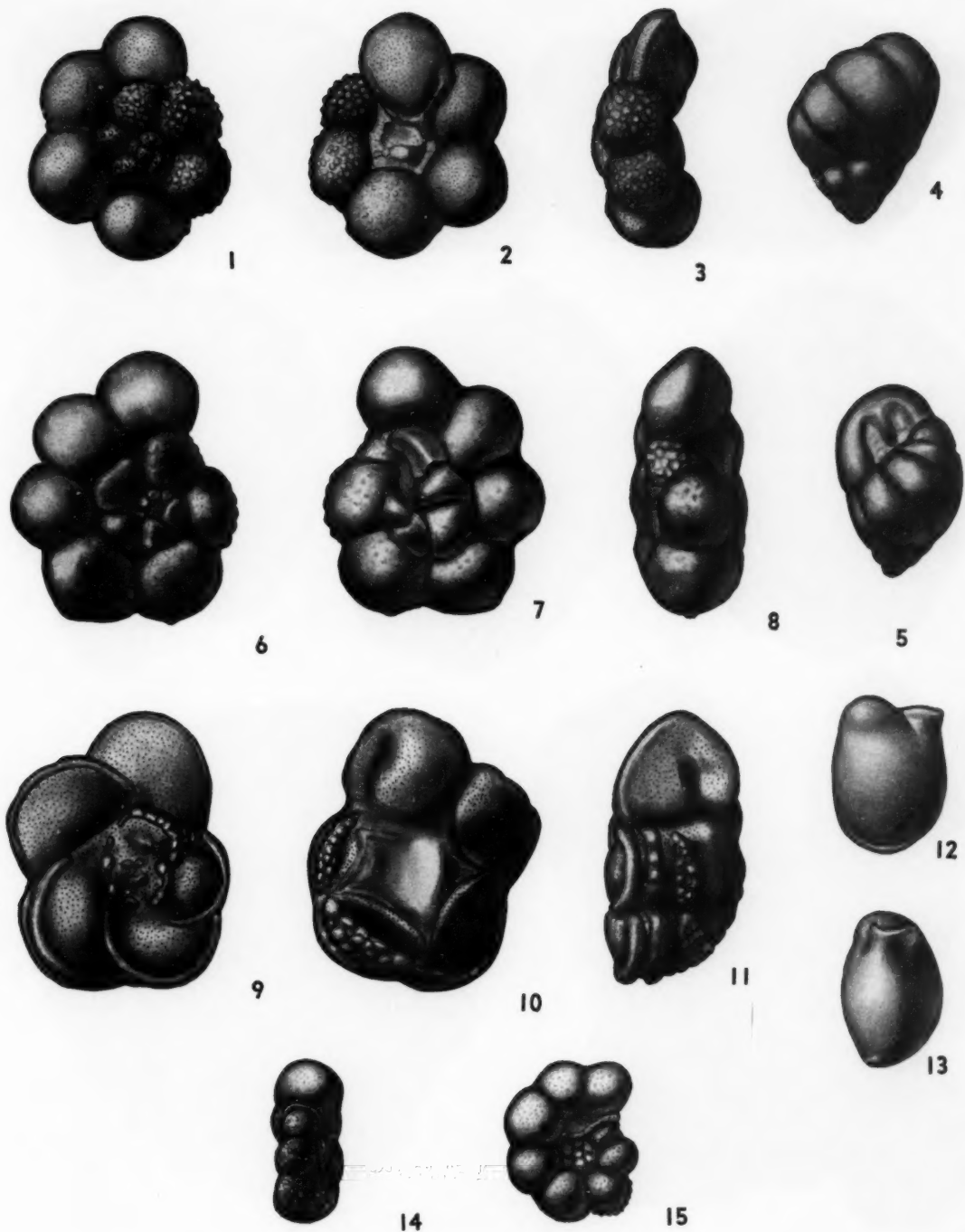
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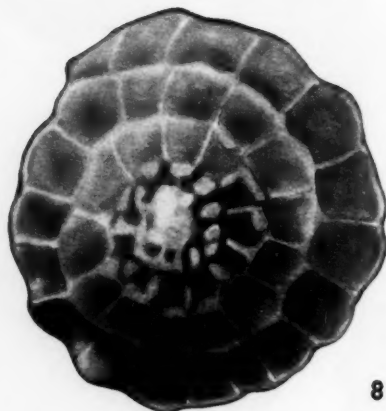
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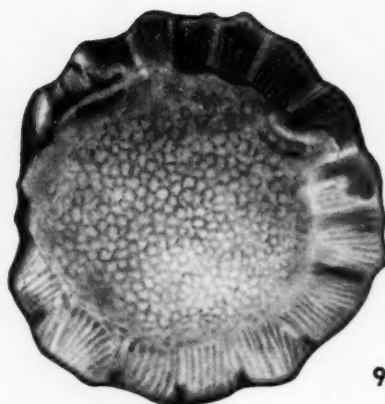
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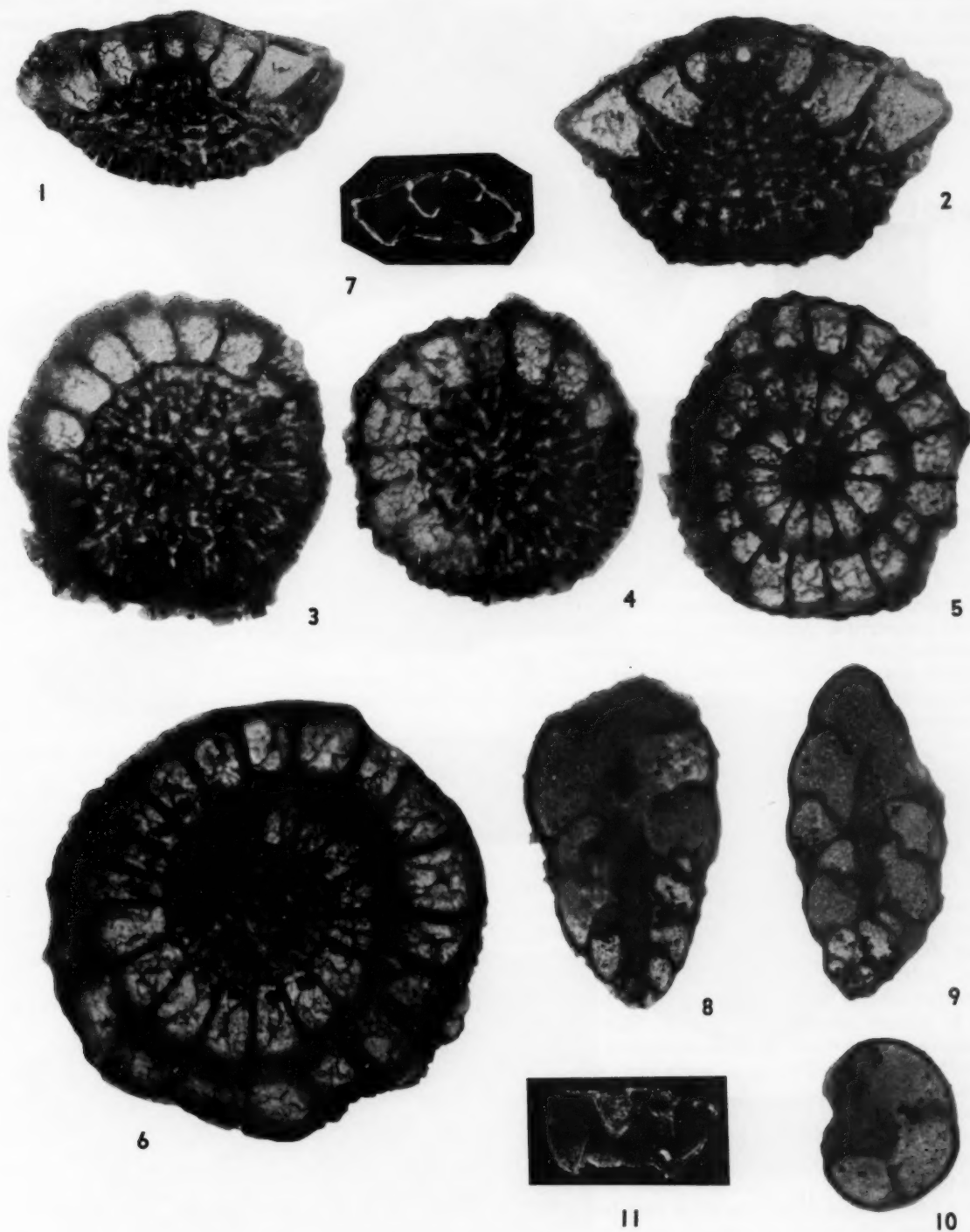
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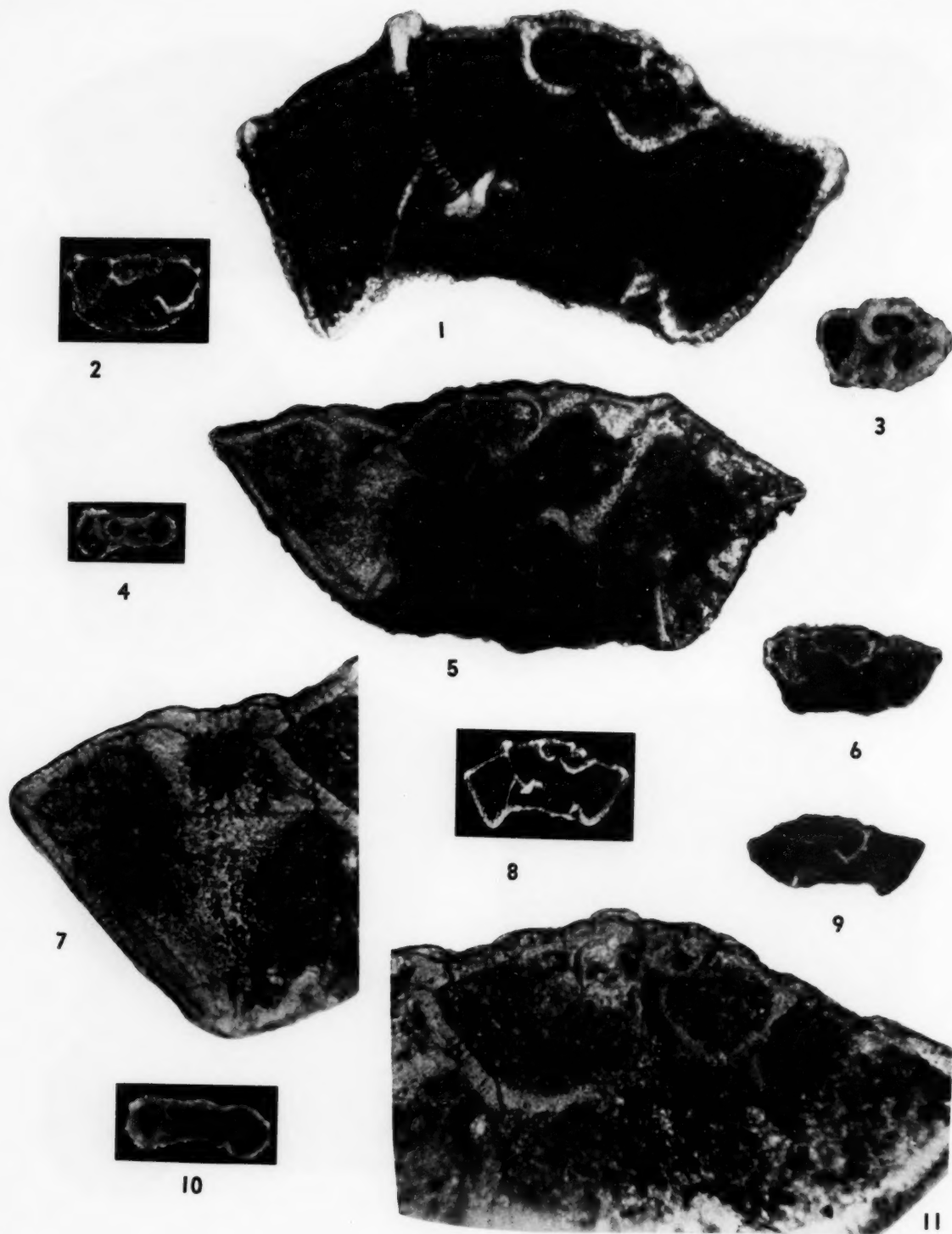


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ABSTRACT: *The genus Truncorotalia Cushman and Bermudez may have developed from the genus Globorotalites. The genotype, Rotalina truncatulinoides d'Orbigny, shows different development of the umbilical cavity, from an open to a totally closed cavity, in specimens from different localities. Thus, it is possible that several fossil species of Globorotalia with a flat dorsal side and a more or less closed umbilicus belong to the genus Truncorotalia. In that case, a closely related series of forms ranges from the uppermost Maestrichtian (or Danian) up to the Recent. The new genus Conorotalites Kaever is synonymous with Globorotalites.*

The genus *Truncorotalia* Cushman and Bermudez, 1949

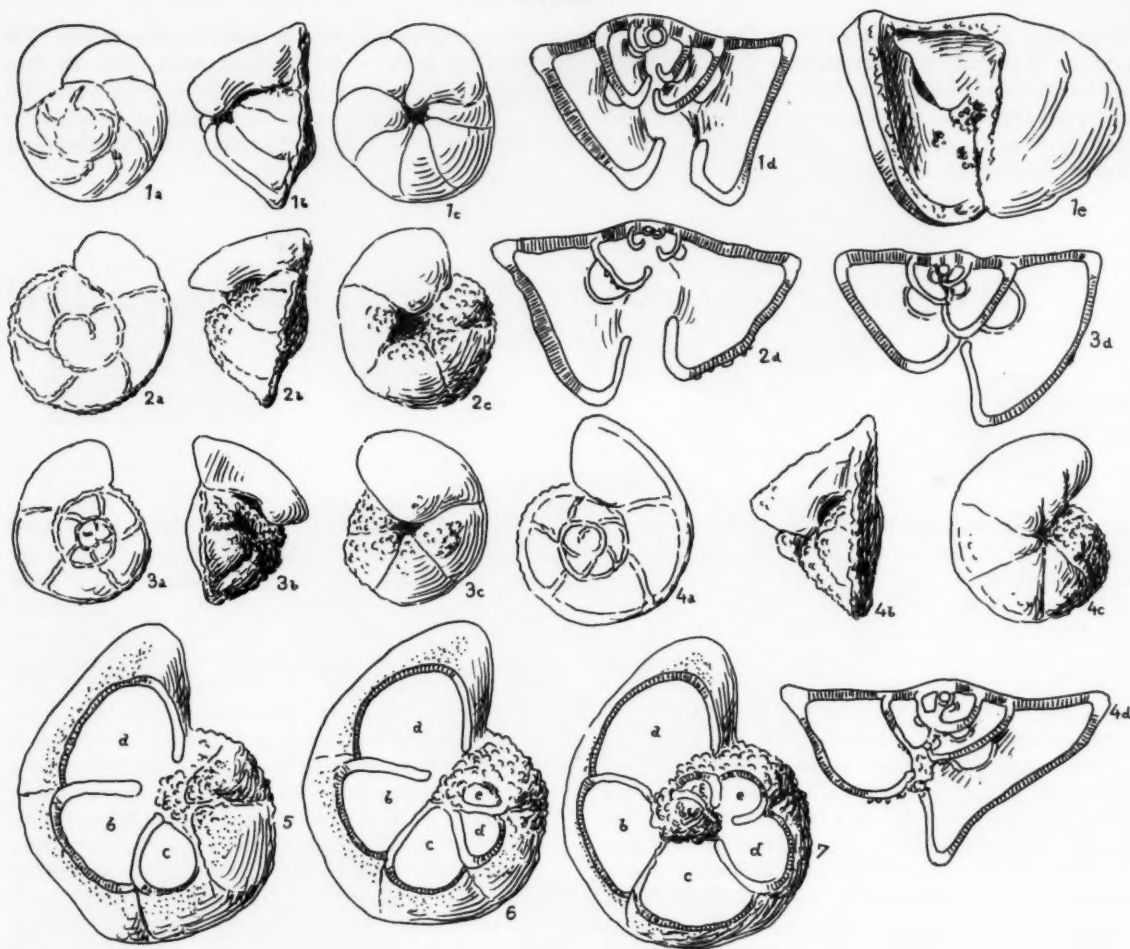
JAN HOFKER

The Hague

Rotalina truncatulinoides d'Orbigny, the genotype of *Truncorotalia* Cushman and Bermudez, 1949, was first described in 1839, from the Canary Islands (d'Orbigny, 1839, p. 132, pl. 2, figs. 25-27). Brady believed that it was identical with *Rotalina micheliniana* d'Orbigny, described from the Craie Blanche of the Paris Basin in 1840 (d'Orbigny, 1840, p. 31, pl. 3, figs. 1-3). The present author analyzed the latter species in 1957 (Hofker, 1957, pp. 401-413), together with many other species of what is now called *Globorotalites* Brotzen, 1942. It can be seen from that study that Brady's belief was not as far-fetched as it may have seemed, as the entire complex of characters of *Globorotalites* and of *Rotalina truncatulinoides* very much resemble each other. In *Globorotalites* there are species with a wide, open ventral umbilicus, such as *Globorotalites brotzeni* Hofker and *Globorotalites subconicus* (Morrow), but there are also forms with only a very small umbilical hollow, such as *Globorotalites multisepta* (Brotzen). The same variation also occurs in different species of *Truncorotalia*. In both genera the dorsal side is flat and the ventral side highly conical; in both, the chamber sutures are oblique on the dorsal side; in both, these sutures lack pores, and pores are also absent on the apertural face; in both, the margin is subacute and lacks pores as well; in both, the aperture is a ventral sutural slit, often widening to a more arched opening; in both, the wall of each chamber bends slightly inward near the marginal rim (compare text-figs. 1d and 2d). There are slight differences between the genera; in *Globorotalites* the pores are often very fine, and the chamber walls are somewhat opaque in transmitted light; in *Truncorotalia*, the pores are slightly more scattered, and the walls are translucent in transmitted light, at least in Recent specimens; in both genera,

however, the dorsal wall of the test is thickened, while the ventral wall remains thinner. In both genera, the poreless tena of the ventral side of each chamber bend upward, forming the umbilical hollow. These tena may become thicker in some species, and then they may fill the entire umbilicus. In *Truncorotalia*, and in *Globorotalites* as well, the septa of the chambers are simple (text-figs. 5-7). A figure of *Globorotalites michelinianus* (d'Orbigny), from the Campanian of Germany, is presented here for comparison (text-fig. 1a-e). In northwestern Germany and the Netherlands, the genus *Globorotalites* became extinct in the lower part of the upper Campanian, but in Belgium and southwestern France, several species of *Globorotalites* have been observed which continued their development into the upper Maestrichtian.

An analysis of *Rotalina truncatulinoides* d'Orbigny, the type species of *Truncorotalia* Cushman and Bermudez (1949, p. 35), will be given in the present paper. Forms resembling d'Orbigny's original figure are found in the southern and tropical Atlantic, the Caribbean, and the Mediterranean, but they are found to differ from each other in several respects when studied closely. A transverse section of a specimen in the *Challenger* collections, from Tristan da Cunha, was given in an earlier paper (Hofker, 1956, p. 372, fig. 4). That form seems closely similar to d'Orbigny's figure. In the present paper another specimen from the same sample is figured (text-fig. 2). It shows about six chambers in the last-formed whorl, with slightly oblique sutures; on the ventral side there is a large hollow, which in transverse section is seen to be a true umbilical hollow (text-fig. 2d).



TEXT-FIGURE 1

Globorotalites michelinianus (d'Orbigny), from the lower Campanian, Blumenauer Strasse, Hannover, Germany: a, dorsal side; b, apertural face; and c, ventral side; all $\times 40$; d, transverse section, $\times 85$, showing the poreless margin and the poreless tena bent upward to form an open umbilicus; e, test with the last-formed chamber removed, $\times 85$, showing the so-called "bipartitor."

TEXT-FIGURE 2

Truncorotalia truncatulinoides (d'Orbigny), Recent, from off Tristan da Cunha; a, dorsal side; b, apertural face; and c, ventral side; all $\times 40$; d, transverse section, $\times 85$, showing the poreless margin and the tena of the chambers bent upward to form an open umbilicus.

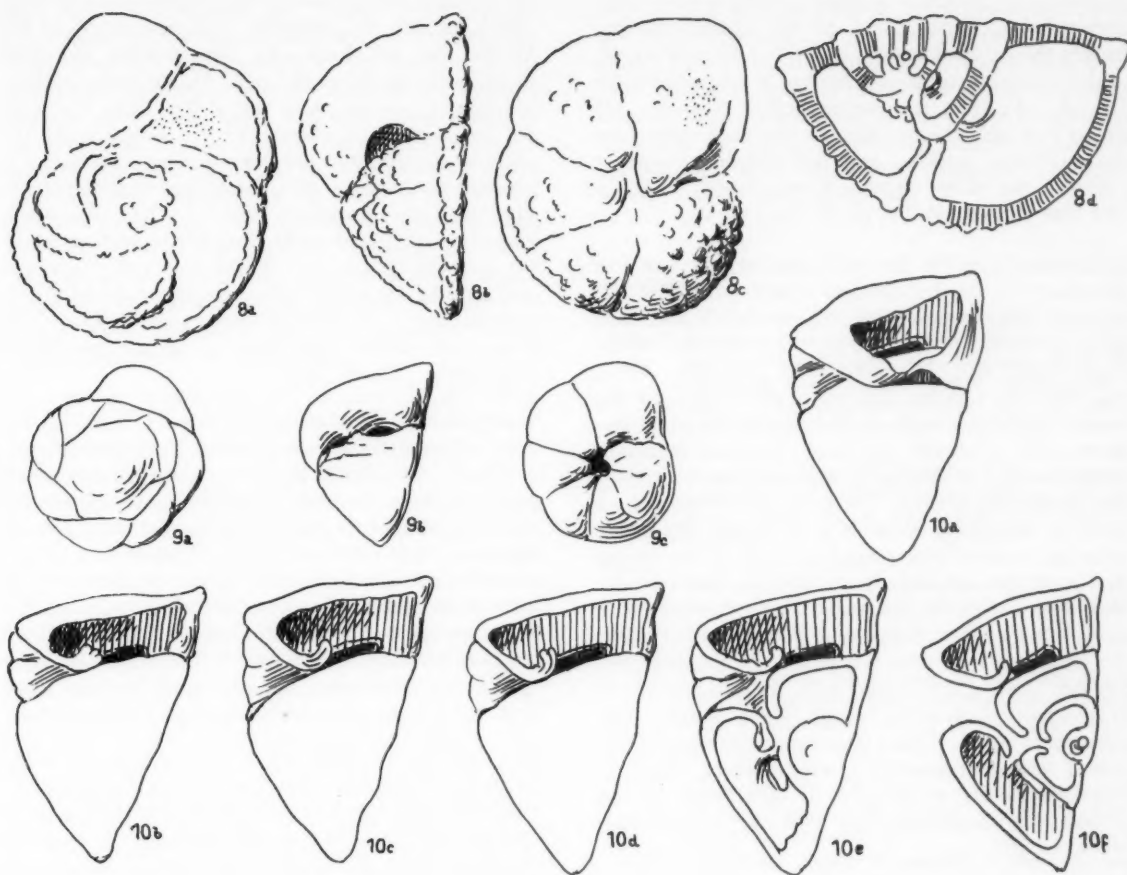
TEXT-FIGURE 3

Truncorotalia truncatulinoides (d'Orbigny), Recent, from the Caribbean off Santa Cruz, in 500 fathoms; a, dorsal side; b, apertural face; and c, ventral side; all $\times 40$; d, transverse section, $\times 85$, showing the nearly closed umbilical cavity.

TEXT-FIGURE 4

Truncorotalia truncatulinoides (d'Orbigny), Recent, from the Bay of Naples; a, dorsal side; b, apertural face; and c, ventral side; all $\times 40$; d, transverse section, $\times 85$, showing the totally closed umbilical cavity and the tena bending upward to form a solid central column.

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TEXT-FIGURES 5-7

Truncorotalia truncatulinoides (d'Orbigny), Recent, from the Bay of Naples: Chambers a-e are shown in a series of horizontal sections beginning from the ventral side, $\times 85$; the septa between the chambers are simple, and adhere to the earlier septa ventrally, then become detached from the central column, forming the aperture, and farther dorsally are once again attached to the central column.

TEXT-FIGURE 8

Truncorotalia mosae (Hofker), from the Chalk Tuff of Maestricht, Netherlands: a, dorsal side; b, apertural face; c, ventral side; and d, transverse section showing the poreless margin and the tena of the chambers bent upward to form the closed umbilicus; all $\times 40$.

TEXT-FIGURE 9

Globorotalites michelinianus (d'Orbigny) forma *multisepta* (Brotzen), from the upper Campanian in a quarry at Hallembaye, Belgium: a, dorsal side; b, apertural face; c, ventral side; all $\times 40$.

TEXT-FIGURE 10

Globorotalites michelinianus (d'Orbigny) forma *multisepta* (Brotzen), the same specimen as in text-figure 9, a series of sections passing through the entire last-formed chamber, $\times 85$; the series shows clearly that Kaever's so-called "bipartitor" is actually only the broken-off portion of the ventral wall of the last-formed chamber attached to the ventral side of the sutural aperture of the previous chamber; in text-fig. 10f, the septum of the previous chamber is nearly reached; in reality, there is no "bipartitor."

Specimens collected at a depth of 500 fathoms near Frederiksted, Santa Cruz, in the Caribbean Sea, mostly show five chambers in the last-formed whorl, and the ventral umbilical hollow is scarcely visible (text-fig. 3). The transverse section (text-fig. 3d) shows that only the last-formed chamber opens into the umbilical hollow, and the opening is rather narrow; the older chambers are closed ventrally (see also Hofker, 1956a, pl. 29, figs. 15-26).

Specimens from the Bay of Naples again show five chambers in the last-formed whorl, and here the ventral cavity is not visible. The author has already given a thorough description, with sections, of the form from the Mediterranean (Hofker, 1932, pp. 129-131, text-fig. 39a-f); in those sections the ventral umbilical cavity is closed, and the chambers show only a septal foramen. Another specimen from the Bay of Naples is figured here including the transverse section (text-fig. 4). However, a series of horizontal sections were made, beginning with the ventral side (text-figs. 5-7). They reveal that even the last-formed chamber is closed at the umbilical cavity on the ventral side (chambers c, d, e), but possesses an opening (the aperture) where the chamber wall does not reach the ventral side. Farther toward the dorsal side, the chamber wall once again reaches the center of the ventral part (chambers a, b). Thus, both transverse and horizontal sections reveal that, in this form, the umbilicus is totally closed and the chambers do not possess any communication with the ventral umbilical cavity.

Although the type specimen of *Rotalina truncatulinoides* d'Orbigny seems to have had a distinct umbilical cavity, as seen in the specimens from off Tristan da Cunha, the Mediterranean forms, which very closely resemble the form from Tristan da Cunha, lack such a cavity. The author does not believe that it would be wise to separate these specimens from the genotype, because a transitional form is found in the Caribbean. The topotype figured by Bolli, Loeblich and Tappan (1957, pl. 10, fig. 3) resembles the Caribbean form more than it does the form from Tristan da Cunha. Unfortunately, no sections were given. The umbilical cavity is very narrow.

Some early Tertiary species with the general features of *Truncorotalia*, such as *Globorotalia aequa* Cushman and Renz, have a closed umbilical cavity, although other forms, such as *Globorotalia velascoensis* (Cushman) distinctly show a wide, open umbilicus, as was demonstrated by the present author (Hofker, 1956b, p. 372, text-fig. 2). A peculiar species,

described as *Globorotalia* (*Truncorotalia*) *mosae* Hofker (1955, pp. 99-101, text-figs. 1-2), was found in the Chalk Tuff at Maestricht, Netherlands, the type locality of the Maestrichtian. In its generic characters that species does not differ from the type of *Truncorotalia*; it shows the flat dorsal side, the oblique sutures, the poreless subacute margin, the more conical ventral side, the arched ventral sutural aperture, the pustulate ventral chamber walls, and the closed umbilicus. Transverse sections show the poreless tena of the chambers bending upward and closing the umbilical cavity, as in the Mediterranean form of *Truncorotalia truncatulinoides*. The pores are distinct but fine, as in all species of *Globorotalia* (text-fig. 8).

Loeblich and Tappan (1957, pp. 1116-1117), recently discussed this species from the Dutch Maestrichtian Tuff Chalk. However, they do not admit any difference between *Globorotalia*, of which the genotype is *Globorotalia tumida* (Brady), and *Truncorotalia*. They believe that *Truncorotalia mosae* possesses an areal aperture (which it does not, as can be seen from the transverse section), but the two apertures reported by Loeblich and Tappan could not be detected in any of the present author's specimens. Moreover, Loeblich and Tappan deny that the species was planktonic, but they presented no reasons for this conclusion, and in any case, is it certain that all forms now assigned to the genera *Globorotalia* or *Truncorotalia* were planktonic? Thus no valid objections were raised by Loeblich and Tappan concerning the taxonomic status of *Truncorotalia mosae* (Hofker). The figures given here strongly indicate a very close alliance between *Truncorotalia mosae* and the Mediterranean form of *Truncorotalia truncatulinoides*. An open or closed umbilical cavity cannot be considered a valid generic criterion.

Thus it is possible to trace the genus *Truncorotalia* from the Danian (or uppermost Maestrichtian) upward throughout the Tertiary and into the Recent. There may be some doubt, however, concerning the ancestry of this genus. One group of species of *Globorotalia* may have developed from late single-keeled species of *Globotruncana*, in which the tena of the chambers show entirely the same shape and characters as those of *Globorotalia* of the type of *Globorotalia tumida*. This statement contradicts the views given by Bolli, Loeblich and Tappan (1957), since their concept of the apertural conditions in *Globotruncana* seems to be based only on external characters, rather than on the inner structure. Another group, the *Truncorotalia* group, may have developed directly from *Globorotalites*;

TRUNCOROTALIA

late *Globorotalites* from the upper Maestrichtian show many characters pointing toward *Truncorotalia*. Bolli, Loeblich and Tappan believe that the whole group of *Globorotalia* was derived from *Praeglobotruncana* Bermudez, 1942, but that genus seems to be restricted to the Lower Cretaceous, and apparently became extinct in the Cenomanian. Bolli, Loeblich and Tappan give its range as up into the Maestrichtian, but they appear to have included many species that cannot belong to this genus. Thus, there remains a considerable gap in the evolutionary series if *Praeglobotruncana* is accepted as ancestral to the Globorotaliidae. There is no such gap in the series *Globorotalites*—*Truncorotalia*.

In a recent publication, M. Kaever (1958) distinguished the Lower Cretaceous forms of *Globorotalites* as a new genus, *Conorotalites*. This genus was differentiated from the Upper Cretaceous forms of *Globorotalites* on the basis of a structure indicated by Kaever as occurring in *Globorotalites michelinianus*, which he called the "bipartitor." Kaever discovered this structure when dissecting the last-formed chamber, as a kind of bridge extending over what he called the aperture. In his description he stated that he believed that the sutural aperture connects with the umbilical opening, and that the bridge divides these two parts of the aperture.

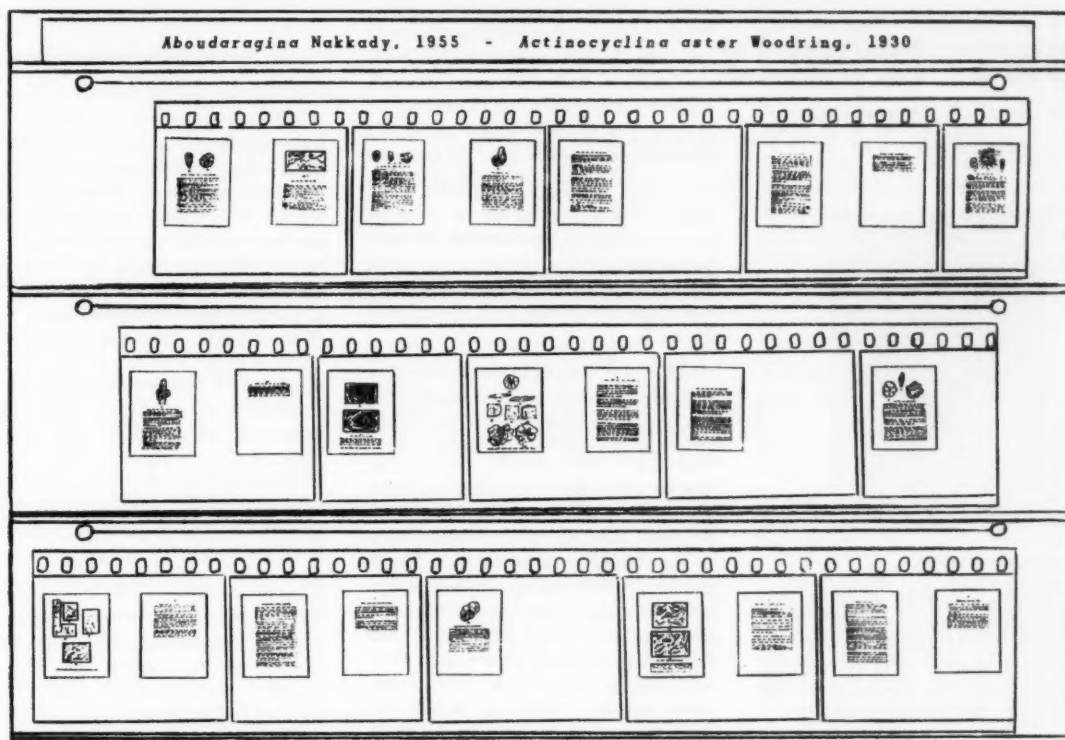
In order to analyze the so-called "bipartitor," the present author sectioned many specimens. Destruction of the last-formed chamber always results in a broken structure closely resembling that figured by Kaever (see text-fig. 1e). A more detailed analysis of a series of sections (the only reliable method of studying the finer structures of the tests of foraminifera), however, reveals that in reality the ventral wall (the upward-bending tenon) adheres to the part of the septum of the former chamber just ventral to the sutural septal foramen (see text-figs. 9–10). When the chamber wall of the last-formed chamber is destroyed, the connection between this adhering part and the rest of the ventral chamber wall is lost, and thus the broken adhering part forms Kaever's "bipartitor." Moreover, our sections show that in all species of *Globorotalites*, including those from the Lower Cretaceous, the sutural septal foramen is separated from the umbilical opening because the chamber wall is connected to the rest of the test between them, as is the case in many other groups of foraminifera with umbilical openings. Thus the test of *Globorotalites* does not differ in this respect from the test of *Globorotalia*, in which the umbilical opening of

the chambers, when present, is also separated from the septal opening, as the sections presented here show. Moreover, this analysis indicates that there is no reason to separate the Lower Cretaceous forms of *Globorotalites* from those of the Upper Cretaceous, and that the genus *Conorotalites* Kaever, based on the presence of a "bipartitor," must be considered synonymous with *Globorotalites*.

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The Catalogue of Foraminifera in microfilm



TEXT-FIGURE 1

The printed edition of the Catalogue of Foraminifera was exhausted in 1958. A new printing cannot be undertaken because of the great cost. The demand for the Catalogue continues, however, and a microfilm edition has been prepared to meet this demand.

The microfilm edition consists of thirty-three 100 foot rolls of 35 mm. film on which the Catalogue, complete through 1958, has been reproduced. More than 1580 genera and 25,275 species are included in this edition.

The rolls of film can be used as issued or cut into strips of four or five frames each and filed in transparent plastic holders (text-figure 1) supplied with each microfilm copy of the Catalogue. These holders can accommodate a total of fifteen frames each, and each frame can be viewed individually in a special flat-bed viewer. Space in which to file supplementary frames can be provided by not filling the holders to capacity initially.

Supplements to the microfilm edition are issued annually and consist of a roll of 35 mm. film. If the transparent holders are being used for the original copy, the supplements should be cut into individual frames and interfiled in the proper places to maintain the alphabetic arrangement. The supplementary frames can be interspliced in the original rolls if a conventional type reader is to be used.

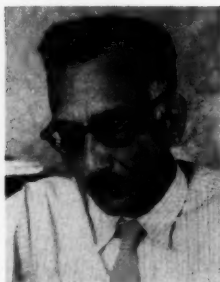
The Catalogue, filed in the transparent holders, can be accommodated in four $5 \times 8 \times 24$ inch file drawers. Self-adhering labelling strips are also supplied with the plastic holders.

This microfilm edition of the Catalogue of Foraminifera is now available on a subscribing membership basis. Inquiries and applications should be directed to the Department of Micropaleontology, The American Museum of Natural History, Central Park West at 79th Street, New York, N. Y.

THE EDITORS.

news reports

INDIA AND BURMA



Y. NAGAPPA

Geology Society of India

The Geology Society of India was formally inaugurated in New Delhi by Shri K. D. Malaviya, Union Minister in January, 1959 during the Indian Science Congress Association meeting. D. N. Wadia presided.

Indian Institute of Technology, Kharagpur

B. Sen Gupta has been engaged in a study of some Eocene and Oligocene larger foraminifera from north western Kutch. These have been found extremely useful in delimiting a number of biostratigraphic zones formed during a marine regression. A paper has been published on this topic ("Zones of the Paleogene of Lakhpat, northwestern Kutch, India," *MICROPALAEONTOLOGY*, July, 1959). Sen Gupta was due to go to Cornell University towards the end of September, 1959. His visit is being sponsored by the United States Technical Cooperation Mission.

B. K. Ghose has completed his studies on foraminifera from Khasi Hills, Assam. From rock sections, 54 species have been identified, including 8 new species and 5 new varieties. The report was submitted as a Master's Technical thesis.

Oil and Natural Gas Commission, Central Laboratories

Palynology Section: Samples from nearly 30,000 feet of test well cores from drillings at Jawalamuki, Hoshiarpur and Cambay have been examined and a correlation established based on the evidence of the microflora.

In Baroda, Bombay State, it was possible to establish correlation of the succession penetrated in some 15 shallow exploratory holes.

Surface samples from various traverses in the Punjab, Himachal Pradesh, Jammu, Uttar Pradesh and Assam have been examined. These studies indicate a floral succession in the Siwaliks, ranging from upper Miocene to lower Pleistocene. In Himachal Pradesh and Uttar Pradesh, Kasauli and Dagshi formations can be placed in the lower Miocene and Subathu formation in the Eocene.

Examination of microflora from the Jurassic to the Miocene formations exposed in Kutch and Kathiawar is in progress.

Some progress has been made in organizing a herbarium for the study of living spores and pollen.

C. P. Varma, palynologist, received training at the Institut Français du Pétrole and submitted a report entitled "Palynological correlation of two bore holes in the Paris Basin."

Prof. C. A. Arnold and B. E. Balme visited the laboratories in January, 1959, and the Palynology Section had the benefit of their advice.

Palaeontology Section: The smaller foraminifera and ostracoda recovered from the two wells at Cambay, Bombay State, have been studied and for the time being, the species

have been given numbers. Eleven faunal zones have been established in this sequence, ranging from Eocene to Recent. Detailed study of the microfauna and microlithology in collaboration with the Petrology Section of the Central Laboratories is in progress on the palaeoecology of the Cambay Basin.

A study of foraminifera and ostracoda of the Assam Eocene succession is in progress.

Study of surface samples from Kutch has shown that *Linderina* is restricted to a definite zone within the middle Eocene.

Eoassilina elliptica Singh, described earlier from the lower Eocene of Palana, Rajasthan, has now been found in the lower Eocene of Bikaner, near Kolayat, and Jaisalmer in Rajasthan.

R. B. Mehrotra returned to India after completing his training in micropalaeontology under M. Lys and N. Grekoff at the Institut Français du Pétrole. He submitted two reports, entitled "Eocene and Oligocene ostracoda of Paris Basin" and "Upper Tertiary and Quaternary foraminifera of Po Valley, North Italy."

Among the distinguished visitors to the Central Laboratories were Prime Minister Jawaharlal Nehru, G. B. Pant, Home Minister, Arnold Heim, F. Horatia, Deputy Minister for Oil Industry in Rumania, and several ECAFE delegates.

University of Lucknow

A. R. Rao is studying the microfossils of the Palana (Eocene) and Warkalli (Miocene) lignites. The macerated samples have yielded a number of pollen grains, spores and

some fungal fructifications referable to Microthyriaceae. Three of these appear to be definitely new to science. A paper describing and illustrating these is in preparation.

Assam Oil Company, Limited, Digboi

Your correspondent submitted two papers during the past year: One, "Foraminiferal biostratigraphy of the Cretaceous-Eocene succession in the India-Pakistan-Burma region" (MICROPALAEONTOLOGY, vol. 5, no. 2, April, 1959) and the other, in press, is "A note on *Operculinoides* Hanzawa 1935." This latter is to be published shortly in Palaeontology. The main conclusions are that *Operculinoides* Hanzawa as constituted now is made up of three distinct groups of forms typically represented by (1) *Nummulites willcoxi* Heilprin (2) *Operculina ocalana* Cushman and (3) *Operculina bermudezi* Palmer. It is shown that (1) can be regarded as a typical *Nummulites*, (2) may be considered as an involute *Operculina* while (3) is a *Ranikothalia*.

Standard Vacuum Oil Company

More than 40,000 feet of subcrop sections from Debagram X-1, Bolpur-1, Ranaghat-1 and Memari-1 of the Bengal Basin have been examined for microlithology, foraminifera, sporepollen and associated microfossil content, to better understand the stratigraphy of the region.

Worldwide index foraminifera of middle to upper Eocene, Oligocene and Miocene ages occur in these subcrop sections. Smaller foraminifera restricted to Upper Cretaceous and Pliocene were also noted. Spores, pollen and hystrichospherids of Upper Cretaceous to Plesitocene age are associated with the foraminifera. Of special interest is the occurrence of index species of *Pellatispira*, *Hantkenina*, *Nummulites*, *Assilina*, *Discocyclina*, *Lepidocyclina*, *Miogyopsinoides* and of the *Globigerinidae*, as well as of *Magnolia*, *Ficus*, *Nymphaea*, *Ara*, *Bombax*, *Olex*, *Terminalia*, *Caesalpinia*, *Barringtonia*, *Sterculia*, *Caryophylla*, *Lygodium*, *Pinaceae*, *Cyperus* and many others.

A preliminary stratigraphic report on the Burdwan X-1, Galsi X-1 and Jalangi X-1 subcrop sections, prepared by B. Biswas, was released for presentation in the 1958 ECAFE petroleum symposium held in New Delhi. It was agreed in principle by the ECAFE delegates from the Far Eastern countries that facilities for comparison of micropaleontologic material within the region should be created for purposes of accurate regional geologic studies.

Geological Survey of India

Examination of Jurassic and Eocene succession of Jaisalmer, Rajasthan, is receiving attention. Several foraminifera belonging to the genera *Ammodiscus*, *Asterigerina*, *Bathysiphon*, *Bulimina*, *Cibicides*, *Dentalina*, *Discorbis*, *Eponides*, *Fronicularia*, *Gaudryina*, *Haplophragmoides*, *Lagena*, *Lenticulina*, *Marginulina*, *Saracenaria*, *Nodosaria*, *Patellina*, *Planularia*, *Sigmolinita*, *Vaginulina*, *Valvulina*, and *Verneuilina* and ostracoda of the genera *Bairdia*, *Cypris*, *Cytherella*, *Cytherelloidea*, *Cythereis*, *Cytheropteron*, *Eucythere* have been identified. The larger foraminifera from the Eocene, *Nummulites atacicus* Leymerie, *Assilina granulosa* d'Archiac and *Alveolina oblonga* d'Orbigny are typical of the lower Eocene.

V. R. Khedker is now palaeontologist in the Geological Survey of India.

Birbal Sahni Institute of Palaeobotany

D. Bhardwaja has completed the study of *Porostrobis zeilleri* Nathorst and its spores. He has also completed the study of miospores from 9 coal seams comprising the succession of Raniganj Stage (upper Permian) in Raniganj Coalfield, India.

G. K. B. Navale has investigated the problem of correlation of the Samla seam from two collieries in East Raniganj Coalfield.

B. S. Venkatachala has completed a detailed work on the *sporae dispersae* from coal seams of Falkenberg Colliery, Lorrain, France.

H. P. Singh is investigating the coals of the upper Permian, Triassic and

Jurassic ages of Europe, India and Australia.

D. Bhardwaja and B. S. Venkatachala are investigating *sporae dispersae* from a lower Carboniferous shale of Spitzbergen and an upper Devonian shale from the United States.

D. Bhardwaja, H. P. Singh, Y. N. Saksena, S. K. Saluja and S. K. Srivastava are working out the palynological correlation of coal seams in East Raniganj Coalfield in a C. S. I. R. Scheme entitled "Palaeobotanical Investigation of India Coals".

K. M. Lele has worked out the microfossils recovered from the Talchir shales at Goraia in the south Rewa Gondwana Basin. The spores are assigned to 13 genera, including a new genus, *Tetraletes*. He is also carrying out the microfloral investigation of the Talchir-Karharbari succession in the Karharbari Coalfield.

Gyan Prakash has macerated a few carbonaceous shales of lower Gondwanas collected in Santhal Parganas, Bihar. He finds that pteridophytic spores are quite common in these shales but the winged spores are rare.

P. K. Maithy is studying the cuticular structure of *Palaeovittaria* and *Noeggerathiopsis*.

Sukh Dev has studied a few carbonaceous shales from the Jabalpur series of the South Rewa Gondwana Basin. He finds that the spores and pollen grains isolated from these shales are similar to those recovered from the Jabalpur outcrops of Narsinghpur district, Madhya Pradesh.

S. K. Roy has studied the microflora obtained from the Umia beds of Cutch. The pteridophytic and coniferous spores are most numerous while the cycadophytic are poorly represented in these beds.

R. N. Lakhanpal, Gurdip Singh and K. M. Sahai Saxena are engaged pollen analytical studies of the Quaternary deposits of Kashmir.

J. Sen is due to return to India shortly from Glasgow after completing his work on the megaspores of the Ayrshire Coalfield. Earlier he worked under Olof H. Selling at the Riksmuseum in Stockholm.

Eight graduate students, working under N. N. Chatterjee in partial fulfilment of their Master of Science degree have been studying the lower Gondwana Coal basins of the Damuda, Auranga, Ib, Pondri, and Brahmini rivers of the Talchir and Rajmahal hills.

Samir Banerjee reported that the Baraker coal measures of the Palast-hali area of the Damuda Basin are of basal Baraker age and comparable with the sequence of the Karharbari beds in. He based his opinion on the floral facies which consisted of *Rhipidopsis ginkoides*, *Gondwanidium* sp., *Voltzia heterophylla*, *Taeniopteris danaeoides*, species of *Sphenopteris* in association with species of sharply pointed spinose forms of *Granulatisporites* (dominant), coarsely punctate *Punctatisporites*, *Reticulatisporites*, *Laevigatosporites* and a small amount of *Pityosporites*.

Basudev Bhattacharyya also reported on the Baraker coal measures and the Raniganji formation of the Auranga valley at Jagaldaga. His study indicated certain changes in the direction of facies components of the floral elements of the Baraker coal measures. He based his conclusions on the occurrence of *Sphenophyllum speciosum*, *Pecopteris ptegoteroides*, *Actinopteris* sp., and a number of cycadean microsporilla together with species of microspores and pollen: *Punctatisporites* 60%, *Granulatisporites* 10-15%, *Pityosporites* 3-10%, *Florinites* 2.5%, *Leuckisporites* 2%, *Laevigatosporites* 1-2%, *Raistrickia* 0.5% and a number of mono- and biseriate bordered pitted tracheids.

Dilip Das reported on the Talchir formation and the coal-bearing Damudas of the Talchir coalfield of Orissa. His work on the microspores and pollen of the three seams at Handiduha indicated that species of

Granulatisporites are at its minimum in the bottom seam but they increase in amount towards the middle and top seams; *Florinites* decrease gradually from bottom to top; *Punctatisporites* decrease in amount in the middle but increase again in the top seam; *Pityosporites* and *Laevigatosporites* follow practically the same order of appearance as *Punctatisporites* but *Lueckisporites* is absent in the middle and the top seam.

J. Banerjee and S. Das reported on the Barakar and Dubrajpur formations of the Brahmini valley of the Rajmahal hills around Masania. The microspores and pollen from the bottom and the top coal seams of the Barakar coal measures showed that *Punctatisporites* decreased from 77% in the bottom seam to 38% in the top seam, whereas the rest of the more important genera showed an increase from bottom to top: *Lueckisporites* from 13 to 37%; *Granulatisporites* from 6 to 17%; *Laevigatosporites* from 0.7 to 3%; *Pityosporites* from 1.7 to 3% and *Florinites* from 0.2 to 1%.

Subinoy Ganguli reported on the microspores and pollen from the basal seam of the Pondri colliery near Chirimiri in Madhyapradesh. He encountered a large number of forms which had a frequency distribution in the following order: *Punctatisporites* 51%; *Granulatisporites* 25%; *Laevigatosporites* 12%; *Florinites* 6%; *Pityosporites* 3%; *Raistrickia* 1.5% and *Lueckisporites* 1%.

BURMA

This is the first time a report is being made of the activities in this country. Dr. Nyi Nyi is in charge of palaeontology at the University of Rangoon and much of his time is taken up in teaching. He has been building up a small teaching and research micropaleontological laboratory since his return from England three years ago. Both the microfossil and literature collections were built up from scratch and he now has a fair sized collection. He has started work on smaller foraminifera of the Pegu System (Oligocene to Miocene) Nyi Nyi is scheduled to visit the

United States on a two months program to study and observe teaching methods of geology in the various universities of the United States. He expects to have the opportunity of discussing problems of higher education in geology.

Burma Geological Department, Rangoon

A Palaeontology Section was started in August, 1959, with U Nita Pe in charge. Nita Pe has collected some Eocene foraminifera from near Pongsau Pass on the Burmese side of the frontier with India. Examination of this material is in progress.

Palaeontological Laboratory, Burma Oil Company, Limited

With the help of one Burmese assistant U Kyi Maung, your correspondent has been in charge of organizing the laboratory since the beginning of 1959. Foraminifera are the only fossils receiving attention at present. Well cuttings from Kyaiklat and Dedaye in the Delta area and from Ondwe in central Burma were examined. The fauna showed considerable variation and correlation was not easy. Surface samples are being examined with a view to establishing faunal zones which might assist in correlation.

Y. NAGAPPA
Assam Oil Company, Ltd.
Digboi, Assam

JAPAN



KIYOSHI ASANO

Micropaleontology in Japan has made steady progress and the news of the past year reflects increased activities.

At the Annual Meeting of the Paleontological Society of Japan, held at Tokyo University on December 6, 1958, Japan's most distinguished paleontologist, Dr. H. Yabe, observed his eightieth birthday with 250 persons attending the celebration. Dr. Yabe is Professor Emeritus of Tohoku University and President of the Paleontological Society of Japan. On this occasion he delivered his presidential address on the geologic range and geographic distribution of the *Desmostyliiformes*, a new order of large mammal, of which many fine skeletons have come to light in Japan's mid-Tertiary. He emphasized the importance of the marine-continental stratigraphic correlation as borne out by the foraminifera found in association with this extraordinary creature which lived in a marine habitat in hippopotamus-like fashion on both sides of the Pacific.

For a number of years the students of foraminifera in Japan have been cooperating in the publication of the journal, *Yokochu* (Foraminifera). This journal was founded as a means of bringing the workers on the group into closer contact with relation to systematic research, discussions of various problems and cooperation in the development of the study of the foraminifera in Japan.

Tohoku University

Professor S. Hanzawa left in September 1958 to study the larger foraminifera at Cornell University. In February he went to New York University to continue his studies, expecting to return to Japan in August 1959. He will retire from active duties in March 1960. At present, plans are being made to publish a commemorative volume in recognition of Professor Hanzawa's great contribution to the paleontology of foraminifera. Outstanding students of foraminifera throughout the world are being invited to contribute to this volume.

Professor K. Asano is continuing his work on the foraminifera dredged from the Japanese continental seas by the S.S. *Soyo-maru*. He has completed Part 5, the *Nonionidae*, of the

series, and has also been studying the Cretaceous and Paleogene foraminifera of Hokkaido and Kyushu of which the preliminary reports were issued in *Yokochu*, nos. 5, 7, 8 and 9. Mr. Y. Takayanagi is now completing his work on the Cretaceous foraminifera of Hokkaido. His studies are directed toward systematic ranges, geological and correlation significance, especially in relation to the ammonite zones hitherto recognized in Hokkaido and their value in time stratigraphic classification.

Mr. M. Murata has published a new interpretation of the geological structure of the limestone plateau based on his study of the fusulinids of the Akiyoshi Plateau in *Yokochu*, no. 9, 1958. Mr. J. Kotaoka is now engaged in a study of the bryozoa from the Pleistocene Ryuku limestone of Okinawa. Professor K. Hatai in the course of his study of fish otoliths from several Pliocene deposits in northern Japan has found a new species similar to *Gadus macrocephalus* Tilesius in each of the deposits in association with other kinds of fishes. Dr. Yabe, Professor Emeritus, has published several papers on the Devonian, Carboniferous and Permian fusulinids of Japan with particular emphasis on their bearing on the boundaries between those systems. These papers are: Carboniferous-Permian boundary in Japan, *Proc. Jap. Acad. Sci.*, vol. 34.; Peculiar geographical distribution of the Onimaru and Akiyoshi faunas in the Japanese Carboniferous (*ibid.*, no. 3); Devonian-Carboniferous boundary in Japan (*ibid.*, no. 4); Thick limestones of the Upper Carboniferous-Permian age in Japan, An interpretation of their mode of deposition (*ibid.*, no. 4); Major division of the Carboniferous in Japan, I (*ibid.*, no. 5); Major division of the Carboniferous in Japan, II, Middle Titibu limestone facies (*ibid.*, no. 6).

Tokyo University

Dr. T. Hanai is making progress on his study of the ostracoda of Japan and has published a monograph on the family *Cytherideidae*, *Jour. Fac. Sci., Univ. Tokyo*, Sec. 2, vol. 9,

pt. 3, 1959. Dr. T. Hamada has been studying the *Halysitidae* since 1937 and has recently published a monograph on Japanese members of the group. He has described several new species giving detailed attention to the inner structure, and has discussed their relationship to the Asiatic and Australian forms as well as the Chinese and Korean forms, *Jour. Fac. Sci., Tokyo Univ.*, Sec. 2, vol. 10, pt. 3; vol. 11, pts. 3 and 4.

Tokyo University of Education

Mr. H. Igo described an interesting branching coral, *Koninckocania*, from the late Paleozoic Ichinotani formation in which is preserved early neanic to gerontic stages. *Jap. Jour. Geol. Geogr.*, vol. 29, No. 4. Elsewhere, he described the fusulinids from the Permian Funafuseyama limestone and the faunal zones they represent, *Jubl. Publ. Comm. Prof. Fujimoto's 60th Birthday*. Professor H. Fujimoto attended the International Carboniferous Congress as a representative of Japan. He read papers on the Carboniferous fusulinids of Japan and their bearing on the boundary problems in stratigraphy. Professor Fujimoto retired from active duties in March 1959. A commemorative volume published in honor of Professor Fujimoto appeared in 1958 in which the following papers in micropaleontology appeared: Mr. S. Akagi in his study of Permian *Porifera* described a new species from the Permian of Hiroshima Prefecture, *Jubl. Publ. Commem. Prof. Fujimoto's 60th Birthday*; Mr. H. Igo and Mr. K. Ogawa described one new species of *Parafusulina* in their joint study of the fusulinids of the Funafuseyama limestone, (*ibid.*). Messrs. N. Yamagiwa and K. Ishii described two new species of the genus *Yabiena* from the Permian of the Shima Peninsula, Mie Prefecture (*ibid.*). Professor H. Fujimoto and H. Igo published a joint paper on the fusulinid zones in the Japanese Carboniferous, *Sci. Rep., Tokyo Daigaku*, Sec. C, vol. 6, no. 53, as well as on the stratigraphic position of the corals in the Carboniferous Ichinotani formation, whereby the faunal zones of that system in Japan have been clarified. *Proc. Jap. Acad.*, vol. 34, no. 3.

Saitama University

Dr. R. Morikawa described a large fusulinid fauna from the Akasaka limestone, among which are many new species. *Sci. Rep.*, Saitama Univ., Ser. B, vol. 3, no. 1. Mr. M. Horiguchi described some calcareous algae from the Permian of the Kitamai massif in Northern Japan, recognizing two new species. *Sci. Rep.*, Saitama Univ., Ser. B, vol. 3, no. 1. Professor R. Endo published his 13th report on the later Paleozoic calcareous algae of Japan in which he recognized one new genus and two new species, *Trans. Proc. Paleont. Soc. Japan*, N.S., No. 31.

Kyoto University

Mr. Y. Nogami has been engaged in a study of the fusulinids from the Maizuru zone in southwest Japan, and he has recently published on the subfamilies Ozawainellinae, Schubertellinae and Neoschwagerinae. *Mem. Coll. Sci.*, Kyoto Univ., Ser. B, Vol. 25, No. 2. Professor J. Makiyama who has been engaged in the study of mammals, molluscs and foraminifera will retire in 1959. In recognition of his many contributions to the geology and paleontology of Japan, a commemoration volume will be published.

Osaka City University

Mr. K. Ishii wrote several outstanding articles during 1958, namely; On the Phylogeny, Morphology and Distribution of *Fusulina*, *Beedeina*, and Allied Fusulinid Genera (*Jour. Inst. Polytech. Osaka City Univ.*, Ser. G, Vol. 4), and Fusulinids from the Middle Upper Carboniferous Itadorigawa Group in Western Shikoku, Japan (*ibid.*, Vol. 4).

Osaka University

Mr. S. Sakaguchi and Mr. N. Yamagiwa described seven new coral species from the late Paleozoic in the southern part of the Tanba District, Kyoto (*Mem. Osaka Univ.*, Lib. Arts Ed., B. Nat. Sci., No. 7). In addition, N. Yamagiwa's paper *Tabeina* from Omura Island, Shima, Mie Prefecture, was published in the Jubilee Publ. Comm. Prof. H. Fujimoto's 60th Birthday.

Hiroshima University

Mr. Y. Okimura in his biostratigraphical and paleontological studies on the endothyroid foraminifera from the Atetsu Limestone Plateau, Okayama Prefecture, Japan, recognized six new species and two new genera. He discussed the geology and faunal zones and gave particular attention to the significance of the faunal change between the Nagoe and Kodani formations. (*Jour. Sci. Hiroshima Univ.*, Ser. C, vol. 2, no. 3). Mr. Tai has been working on the Miocene stratigraphy of southwest Japan based upon the foraminifera. This work has been completed and is expected to be published at a near date in *Science Reports of the Hiroshima University*.

Tokyo Gakugei University

Dr. M. Kanuma published two works on the stratigraphy and paleontology of the southern part of the Hida Plateau and the Northeastern Part of the Mino Mountainland, one in *Bull. Tokyo Gakugei Univ.*, vol. 9, and another in *Jubl. Publ. Commem. Prof. H. Fujimoto's 60th Birthday*. The paper in the former journal deals chiefly with the genus *Triticites*, and the latter with the geology of the two regions.

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POLAND



FRANCIZEK BIEDA

Publications on micropaleontology in Poland which appeared from September 1958 to August 1959 are

chiefly concerned with foraminifera. They are mostly short notices containing lists of species, some of which are included in papers in geology written by other authors.

Miss S. Duszynska described seven species of foraminifera, among them four new species from the Couvinian from Wydryszów (Holy Cross Mountains). These are arenaceous foraminifera in which the tests of two species are built of fine carbonate particles. (*Acta Palaeontologica Polonica*, vol. 4, no. 1, 1959).

S. Liszka has written on the foraminifera of the lower Carboniferous near Krakow. This microfauna of the upper Visean age consists of ten species of which one is new. (*Rocznik Polskiego Towarzystwa Geologicznego*, vol. 28, no. 2, 1958).

H. Jurkiewicz, in a work with two other co-authors lists the foraminifera of the Lower Carboniferous age from the Bratkowice bore-hole northwest of Rzeszow. It has appeared only in Polish (*Przegląd Geologiczny*).

Miss H. Wolńska has made a detailed study of the species, *Agathammina pusilla* (Geinitz), from the lower Zechstein in the Sedeten and Holy Cross Mountains. The author is interested in the morphology of the test, has identified the growth stages and described form A and form B. On the basis of her research, she made a new diagnosis of the genus *Agathammina* as well as a new description of its genotype. (*Acta Palaeontologica Polonica*, vol. 4, no. 1, 1959).

Thus far there is little information on the Jurassic foraminifera. Mrs. W. Bielecka is co-author with Miss Z. Dabrowska on a work on the stratigraphy of Malm in the region of Kamień Pomorski (north-west Poland). W. Bielecka gives the result of her analysis of the microfauna of the upper Jurassic from the Astartian to the Purbeckian. There was only a scanty microfauna in older horizons of the Dogger?-Argovian? age and in younger horizons of the Neocomian. W. Bielecka has found that this microfauna is composed chiefly of calcareous foraminifera.

fera and appears in six different zones, extending in time from the Astartian to Neocomian. The richest assemblages occur in the Bononian; the ostracoda are most numerous in the Purbeckian and Neocomian. Microfauna assemblages found in this profile agree on the whole with assemblages of microfauna in the upper Jurassic of Central Poland. (Instytut Geologiczny, Bull. No. 142, Warszawa 1958). The same author, W. Bielecka, includes lists of foraminifera from upper Kimmeridgian in the work of C. Kowalski that refers to the Jurassic and Cretaceous in the western margin of the Łódź Basin in the environs of Burzenin on the Warta River. (Instytut Geologiczny, Bull. No. 143, 1958).

J. Blaszyk gives a list of foraminifera from the middle Bononian from Brzostowka near Tomaszów Mazowiecki on the Pilica River. This fauna consists almost entirely of calcareous foraminifera, and occurs in a sedimentary series, which in its lower part is comprised of dark clays, and in the upper part of yellowish limestones. (Kwartalnik Geologiczny, vol. III, No. 3, 1959).

In a notice published in Polish Mrs. O. Pazdrowa (Olga Pazdro) discusses the importance of research on variability in foraminifera, quoting examples referring to calcareous foraminifera of the Jurassic. (Przegląd Geologiczny no. 12 1958).

R. Osika published a short paper on the microfaunas of the Polish Mesozoic discussing the lower Cretaceous sediments in the region of Izbica, Kujawy, Central Poland. The micropaleontological specimens were determined by W. Bielecka (Ostracoda of the Purbeckian) and Miss J. Szejn (Foraminifera of the Valanginian and Hauterivian) (Kwartalnik Geologiczny, vol. 3, no. 2, 1959).

A. Pieniazek gave a list of foraminifera of the Lower and Upper Cretaceous in the work of J. Stemulak on the geological structure of the region of Szamotuły and Oborniki, in the western part of Poland (Kwartalnik Geologiczny, vol. 3, No. 2, 1959).

Cz. Pachucki in his work on the Cretaceous in the basin of the Nysa Klodzka River in the Sudetic region gives a list of foraminifera determined by him of the lower Emscherian of this region (Annales Universitatis Mariae Curie-Skłodowska, Section B, vol. 12, 1959).

Two co-authors, Władysław Pozaryski and Mrs. Krystyna Pozaryska, published (Annales de la Société Géologique de Belgique, vol. 82 Liège 1959) a comparative study on Cretaceous stratigraphy in Poland and Belgium, taking special account of micropaleontological evidence.

There is a short but important note by S. Geroch on the stratigraphic importance of arenaceous foraminifera in the Carpathian Flysch. The author lists the arenaceous foraminifera occurring in the Silesian series in successive formations constituting a profile beginning from the Valanginian to the Eocene. He gives the stratigraphical distribution of 26 foraminifera species, and stresses the significance of the appearance of index species. He describes several species, among them a new one. (Paläontologische Zeitschrift, vol. 33, no 1-2, 1959).

Mrs. J. Liszkowa (Janina Liszka) in her joint work with, M. Książkiewicz gives a list of foraminifera of the sub-Silesian series from Golezów in Cieszyn Silesia. The profile begins with the Lower Cretaceous and ends with the Eocene. (Kwartalnik Geologiczny, vol. 3, no 1, 1959). The same author (J. Liszkowa) (Instytut Geologiczny, Bull. no. 131, 1959) also gives a description of foraminifera from beds with exotics at Bachowice near Wadowice on the Carpathian margin. These beds were the subject of an extensive study by M. Książkiewicz who found and described a rich *Globotruncana* fauna derived from rocks with exotics; J. Liszkowa worked on foraminifera occurring in rock containing exotics; marls, marly clays, red shales and green shales. The microfauna consists of calcareous and arenaceous foraminifera, the former appearing in clays, the latter in shales. The foraminifera fauna shows that the beds with exotics were deposited

from the Campanian to the upper Eocene. From the Danian to the Paleocene older formations were eroded and redeposited; their fossiliferous content point to a middle Jurassic source. The work contains descriptions of 22 species and varieties, with one new species determined; seven tables of photographs of fossils are included.

H. Kozikowski collected bibliographic references from the literature about the appearance of foraminifera in the Flysch of the Central Carpathian Depression between Zmigród and Sanok. This work was published in Acta Geologica Polonica, vol. 8, no 4, 1958). The list of index species is of particular interest.

M. Książkiewicz (Kwartalnik Geologiczny, vol. 2, no 4, 1958) lists the foraminifera of Maestrichtian age of Kamionna south of Bochnia. Those foraminifera appear in the sediments at the contact with the volcanic rock (andesite) confirming the age of volcanic activity in that part of the Carpathians through paleontological evidence.

Other authors interested in rocks of volcanic origin in the Carpathian Flysch likewise call attention to appearance of foraminifera as a means of defining the age of those volcanic rocks. Two authors, T. Wieser and K. Zytka (Kwartalnik Geologiczny, vol. 3, no 2, 1959) list the foraminifera determined by Miss J. Blaicher from the sub-Magura beds in the Zywiec region. Foraminifera assemblages appear in the shales near the rocks described as tufoids; the age of these assemblages is lower and middle Eocene. Mrs. J. Morgiel wrote (Instytut Geologiczny, Bull. No. 131, 1959) on foraminifera microfauna from the Babica clays near Rzeszów; these formations are a part of the Skole series, otherwise Skiby series. Up to now the age of these clays was defined as Paleocene to lower Eocene. The author found in those clays two foraminifera assemblages which signify a slightly older age determination; one appears in the lower beds and consists of arenaceous fo-

raminifera, but the other assemblage containing calcareous and arenaceous foraminifera appears in the higher strata. It is significant that calcareous-arenaceous assemblages of the upper layers contain more forms of older age than assemblages composed of arenaceous foraminifera appearing only in the lower beds. The latter assemblages may be defined as Paleocene, while the assemblages from the upper beds ought rather be acknowledged as Upper Cretaceous assemblages. Investigation of the bathymetric distribution of foraminifera indicates that calcareous foraminifera from the upper beds show forms living in shallow, warm water. The appearance of those foraminifera in a geological profile containing sediments of deeper water is explained by the author as caused by transport of shallow water sediments into the area of deeper water, as suggested by S. Bukowy (1955). The appearance of older forms in younger beds is explained by secondary displacement of foraminifera. The author described a number of species and included illustrations.

H. Jurkiewicz in his joint work with P. Karnkowski the results of research on foraminifera of the *Inoceramus* beds in the Magura Nappe. The geological and micropaleontological research of these authors is related to earlier studies, i.e. those of J. Grzybowski (1901) and M. Dylazanka (1923). In the series investigated, the upper part of the *Inoceramus* series, the authors describe a microfauna mostly arenaceous, which appears in a complex consisting of sandstone with intercalations of shales at the lower part of the series. This microfauna is longaged and the authors give the age of this sandstone complex only in general terms saying that is Upper Cretaceous. Higher up there is a shale series which they call the Swiatkowa beds, it forms a transition from the *Inoceramus* beds to the variegated shales beds. The Swiatkowa beds contain only arenaceous foraminifera, their age is defined as Paleocene. The lower part of the variegated shales (red and green) contains arenaceous foraminifera of lower or perhaps

middle Eocene (Acta Geologica Polonica, vol. 9, no 1, 1959).

H. Jurkiewicz gives another report in Polish namely of the appearance of foraminifera in the Sub-Magura beds and the Magura beds in Pielgrzymka south of Jaslo; the appearance of calcareous foraminifera in the Flysch of the Magura beds is an important observation. (Przegląd Geologiczny, no. 5, 1959).

F. Bieda and M. Ksiazkiewicz write in a joint note on larger foraminifera of the Polish Carpathian Flysch. The authors discuss the question of the age of the Babia Góra sandstone. On the basis of determinations by the senior author who gave lists of larger foraminifera from Babia Góra sandstone and from lower beds, the authors correct the determination of other authors of the age of the Babia Góra sandstone as Paleocene-Lower Eocene and extend this sandstone into younger part of Eocene, namely its sedimentation begins in some regions toward the end of Lutetian, in others only in the lower Priabonian, the authors are of the opinion that the Babia Góra sandstone is equivalent to the Magura sandstone. (Kwartalnik Geologiczny, vol. 2, no. 4, 1958).

F. Bieda published (Instytut Geologiczny, Bull. No. 131, 1959) lists of larger foraminifera (*Nummulites*, *As-silina*, *Spirocyclus*) of the Magura series of the Polish Carpathians between Żywiec and Nowy Sącz. The larger foraminifera faunas of this series represent four different stratigraphic zones; according to the author's nomenclature from 1946 they are zones 3, 4, 5 and 6. In zone 3 (lower Eocene with *Nummulites planulatus*) three sub-divisions might be provisionally instituted, namely 3^I = Lower Ypresian, 3^{II} = Upper Ypresian and 3^{III} = transition between Ypresian and Lutetian. The author describes several species of *Nummulites* and adds two tables of microphotographs. The same author published a note on larger foraminifera from the upper Eocene of Velka Causa in Slovakia. He gives a list of species determined and describes two little known species.

(Geologické práce, No. 53, Bratislava 1959).

S. Alexandrowicz published a note on the foraminifera of the Polish Miocene (Kwartalnik Geologiczny, vol. 3, no. 3, 1959) with a list containing 160 species, mostly calcareous foraminifera derived from the uppermost lower Tortonian from Mazankowice near Bielsko (Silesia).

F. Adamczak has published on the ostracoda. The author is studying the problems of phylogeny in the light of his research on the ontogeny of nine species of Devonian ostracoda (*Kozłowskiella* and *Poloniella*) from the Holy Cross Mountains. (Acta Palaeontologica Polonica, vol. 4, no. 2).

In palynology we report some notes giving lists of spores and pollen. Miss J. Dyakowska gives information about some sporomorphs of Coniferae from the Grojec clay (Liassic). (Verhandlungen der vierten Internat. Tagung der Quartärbotaniker 1957. Veröff. Geobotan. Institut Rübel in Zürich, No. 34). The same author discusses the pollen of the genus *Abies* of the Quaternary of Poland from the interglacial deposits of the Mazovian and Eemian age. (Acta Biologica Cracoviensia, Serie: Botanique, vol. 1, 1958).

The appearance of the first handbook of palynology in Polish is an important step for Polish science. This handbook by J. Dyakowska, published in Warsaw in 1959, contains many illustrations of pollen from the Pleistocene, as well as data and research on spores and pollen from ages older than the Pleistocene. Mrs. M. Lańcucka-Środoniowa discusses fern megaspores of the genera *Silvinia* and *Azolla* from the Miocene in north-east Poland in Rypin near Dobrzyn. (Acta Biologica Cracoviensia, Serie: Botanique, vol. 1, 1958).

From the Quarternary, S. Gilewska and L. Stuchlik describe pollen from the Pre-Warta Interstadial at Brzozowica near Będzin. Mrs. M. Ralska-Jasiewiczowa mentions pollen from the Riss Interstadial in Labedy in Silesia. Mrs. W. Koperowa describes

pollen from the peat-moor of the late Glacial age in the environs of Nowy Targ. *Monographiae Botanicae*, vol. 7, 1959.

S. Nakonieczny has found and discussed, sea diatoms which are of Tertiary age by which appear redeposited in the Quaternary in Dębowiec near Lublin. Tertiary formations containing these diatoms are not to be found in East Poland where they seem to have been completely eroded away (*Annales Universitatis Mariae Curie-Skłodowska*, Section B, vol. 12, no. 3, 1959).

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PORTUGAL



JAIME MARTINS FERREIRA

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Last year the drilling activities of the Companhia dos Petróleos de Portugal were transferred to the northern part of Mondego Basin, between Leiria and Figueria da Foz where the Liassic and Dogger formations predominate. Our micropaleontological investigations consequently have been directed toward these

formations. The detailed investigation of microfauna on outcropping sections, stratigraphically well known, and its comparison with the fauna shown by the different sections reached in drilling, enabled us to formulate ideas on the microfauna belonging to some levels and to determine its stratigraphy with a certain safety margin.

Although the micropaleontological investigation of the Dogger formation is not yet finished, it has furnished some valuable information. A resumé of the most important conclusions drawn from our research work follows: The most important fact to be mentioned is the occurrence, between 200 and 250 meters above the base of Dogger, of a typical microfauna composed of different species of *Martinottiella*, *Textularia* and *Cuneolina*. In particular, the species from this last genus have been recognized as good characteristic foraminifera of the Dogger.

In the Liassic, there are also several forms which bear considerable stratigraphical importance. At the top of the Liassic, in this area (north Mesozoic Basin) we find in a general way a rich microfauna, either foraminifera or ostracoda, in which there are abundant specimens of *Lenticulina munsteri*, *L. subolata*, *L. faveolata*, *L. varians*, *Cytherella* sp., different species of *Paracypris*, *Bythocypris* and *Prognocythere*. The boundary between the upper and middle Lias (Toarcian-Charmouthian) is marked mainly by the great abundance of *Polycopse* sp., and several specimens of *Bythocypris* and *Cytheropteron*.

We can consider *Ogmoconcha amalthei* Quenst, a characteristic species for the Charmouthian which has never been found in Portugal in other formations. In the Sinemurian there are different types of *Lingulina*, particularly several specimens of *Lingulina tenera* Born, of *Haplocytheridea* and of *Chytheropteron*. Our research on these formations is progressing and it is probable that we will soon have a reliable microstratigraphic column.

Direcção dos Serviços de Salubridade

Dr. Veiga Alves and your correspondent are now studying the foraminifera of the Miocene of Portugal. With this in mind they have already started to contact micropaleontologists in other countries in order to effect on exchange of tertiary already determined to age; these will be used as a basis of comparison. Due to the small number of investigators in micropaleontology in Portugal, new publications are relatively few since our last news report. Those which have appeared are as follows:

Four papers by J. M. Ferreira and A. T. Rocha: 1955, Sur la découverte de "Lagens X" au Portugal. *Com. Serv. Geol. Portugal*, T. 36; 1955, II Contribuição para o estudo dos foraminíferos fósseis do Túnel do Rossio. *Bol. Mus. Lab. Min. Geol. Fac. Ciências*, 60. no. 23; 1957, Foraminíferos do Senoniano de Catumbela. *Rev. Garcia de Orta*, vol. 5, no. 3; 1958, Observações Geológicas e Paleontológicas sobre a Serre da Arrábida. *Publ. Liga Prot. Nat.*, 14.

Two papers by A. T. Rocha and J. M. Ferreira: 1956, Algumas observações micropaleontológicas sobre o Cenozoico de Lisboa., *Rev. "Ciência"*, no. 13; 1957, Contribuição para o Estudo dos Foraminíferos do Terciário de Luanda. *Rev. Garcia de Orta*, vol. 5, no. 2.

The following micropaleontological notes were presented to the 23rd. and 24th. Luso-Espanhol Congress for Science Progress held respectively in Coimbra and Madrid in 1956 and 1958: Three notes by J. M. Ferreira: 1956, Algumas observações paleontológicas sobre a presença do Género *Elphidium* Montfort, 1808, em Portugal; 1956, Nota micropaleontológica sobre o Oligocénico de Seixalinho; 1958, Foraminíferos do Miocénico da Ribeira d'Ainía (Arrábida) - D.S.S.; two by A. T. Rocha, 1956, Observações micropaleontológicas sobre uma sondagem dos arredores de Peniche; 1956, Sobre a ocorrência do Género *Lagena* Walker and Jacob 1798, em Portugal; one by R. J. Da Veiga

Alves and J. M. Ferreira, 1958, Contribuição para o conhecimento do Miocénico de Aljezur (Nota prévia), D.S.S.; one by J. M. Ferreira and M. M. V. Casteló, 1956 Diatomáceas fósseis de Alfárim, and one by M.M. Castelo M. Ferreira and J. M. Ferreira; 1958 Nota sobre a Microfauna vindoboniana da Praia do Rocha Rocha, D.S.S.

In May 1957, your correspondent and his wife had the pleasure of meeting the great Spanish micropaleontologist, Mr. G. Colom, from whom they received generous and helpful advice. It is a pity that contacts such as this one, cannot be more frequent.

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UNITED STATES - ROCKY MOUNTAIN REGION



DANIEL J. JONES

Micropaleontologists in the Rocky Mountain region have been quite active in various fields during the past 12 months. Research activity among college and university staff members, graduate students, and among the oil companies exhibits a wide variety of interests. Research on palynology of the Carboniferous and of the Cretaceous and Tertiary has occupied a considerable portion of the research activity, and interest continues in the use of endothyroid foraminifera and fusulinids in stratigraphic mapping of the late Paleozoic beds as evidenced in many papers and current research activities.

L. G. Henbest reports a very interesting study of the upper Paleozoic foraminifera in the Hartville area of Wyoming (Wyo. Geol. Ass'n., 13th Annual Field Conference Guidebook, p. 122-131). In this significant paper he deals with the zones of *Endothyra*, *Millerella*, *Paramillerella*, *Profusulinella*, *Fusulinella*, *Fusulina*, *Wedekendellina*, *Waeringerella*, *Serpulopsis*, *Ammovertella*, *Calcitornella*, *Orthovertella*, *Plummerinella* and similar genera of late Paleozoic foraminifera. He concludes that this interesting assemblage occurred in very fertile shallow marine waters but perhaps in the subphotic depth horizons.

In describing the stratigraphy of the Oquirrh formation in the lower portion of the type area and near Logan, Utah, Paul W. Nygreen (Utah Geol. Min. Surv., Bull. 61, 1958) lists the occurrences of fusulinid foraminifera in many zones of the Pennsylvanian-Permian Oquirrh formation and suggests that the cyclic nature of the Oquirrh sedimentation is borne out by the recurrences of fusulines horizons.

Three papers describing conodont faunas from various portions of the Paleozoic of the Rocky Mountains appeared during the past year. G. L. Stone and W. M. Furnish, of Iowa State University describe 19 genera and 29 species of conodonts from the Big Horn dolomite of Wyoming. (Jour. Pal., vol. 33, no. 2, 1959, p. 211-228). The new genus, *Pristognathus* is erected and four new species are included in this new genus. A comparison of the conodont fauna of the Big Horn with those of other areas suggests a pre-Richmond age for the fauna. Dwayne D. Stone, a graduate student at the University of Utah published in the Compass of Sigma Gamma Epsilon in 1959, a brief paper entitled "Taxonomic Key to the Conodont Genus *Streptognathodus*." The paper is well illustrated and presents a key to the various species of the genus *Streptognathodus*. Mr. Stone is doing this work as a part of his doctoral thesis on Pennsylvanian conodonts from southeastern Utah. Additional information on

the fascinating conodonts from the Triassic of the western United States is presented by David L. Clark (Jour. Pal., vol. 33, no. 2, p. 305-312). Dr. Clark, of the Geology Department of Southern Methodist University, describes and illustrates a conodont fauna from the Meekoceras zone of the Triassic Thaynes limestone of eastern Nevada and west-central Utah. The fauna includes species of *Gondolella*, *Hindeodella*, and two new genera *Furnishius*, and *Parachirognathus* are established.

Increasing use of endothyroid foraminifera in stratigraphic work is evidenced by the work of A. K. Armstrong, (Jour. Pal., vol. 32, no. 5, p. 970-976) entitled "Maramecian (Mississippian) endothyroid Fauna from Arroyo Tenasco Formation, Northern and Central New Mexico". In this significant paper Mr. Armstrong, of the University of Cincinnati, describes and illustrates middle Mississippian endothyroid foraminifera from north-central New Mexico and several new species are described and illustrated of the genus *Granuliferella*, *Endothyra*, and *Plectogyra*. Mr. R. B. Woodland, of Brigham Young University describes and figures species of *Plectogyra*, *Endothyra*, *Granuliferella* from the Mississippian, of central Utah, in "Stratigraphic Significance of Mississippian Endothyroid Foraminifera in Central Utah" (Jour. Pal., vol. 32, no. 5, p. 791-814). In this paper, Dr. Woodland names 8 new species, he shows phylogenetic trends of species in Utah and suggests a shallow benthonic environment with some selective sorting of the forms found. He also suggests catastrophic killing off of large populations to account for flood occurrences of endothyroid foraminifera in the Mississippian of Utah. Mr. John E. Welch of Colorado Western College, Gunnison, published a paper on the "Faunozones of the Pennsylvanian-Permian of the Paradox Basin", (Intermountain Assoc. Petrol. Geol., 9th Ann. Field Conference Guidebook, 1958, pp. 153-162), in which he describes and illustrates the fusulinids and corals which serve as guide fossils of the Marrowan, Atokan, Des Moinesian,

and Missourian rocks of the Paradox Basin, Utah.

Two papers appeared during the past year on miscellaneous microfossils. Mr. T. G. Terry and R. C. Gutschick of Notre Dame University in a paper entitled "Bryozoans from the Amsden Formation, Southwest Montana", (Jour. Pal., v. 33, no. 2, p. 313-322), describe and illustrate nine species of bryozoans from the Mississippian Amsden formation of southwestern Montana.

Professor J. K. Rigby of Brigham Young University published on the lower Ordovician graptolite faunas of western Utah (Jour. Pal., vol. 32, no. 5, 1958, p. 907-917). He describes and illustrates graptolites from many of the Ordovician stratigraphic units, of central and eastern Utah. Faunas include species of *Dictyonema*, *Desmograptus*, *Dendrograptus*, *Phlograptus* and *Didymograptus*. The graptolite zones recorded by Dr. Rigby were correlated with previously established zones of trilobites in the same sections.

Research on non-marine microfossils during the past 12 months includes a significant paper by Dr. I. G. Sohn of the U. S. National Museum, entitled, "Middle Mesozoic Non-Marine Ostracods of the Black Hills" (Wyo. Geol. Assoc., 13th Annual Field Conference Guidebook, 1958, p. 120-126), Sohn demonstrates the use of non-marine ostracods in separating the Morrison formation from the overlying Dakota in the Black Hills region. The Morrison formation contains no notched genera of the sub-family Cypridininae. Species are described of the genus *Cypridea*, *Pseudocypridina*, and the genus *Theriosynoecum*.

University of Arizona

Professor Halsey W. Miller reports that he and his colleagues are now occupying their new geology building and he is enjoying a new micropaleontologic laboratory, classroom and storage facilities. Their equipment consists of 17 binocular microscopes and a microscope with oil immersion lenses. Enrollment in the class in micropaleontology has in-

creased to 14 the first semester and 9 the second semester. Also, three research problems are underway and Mr. John DeFato is completing his Master's thesis on a study of Silurian microfossils from Wisconsin. At the present time Dr. Miller is trying to obtain a grant to study the fusulinids of Sonora and southern Arizona. If he is successful, two research assistantships will be established at the University of Arizona in micropaleontology for a period of two years, and it is hoped that this will result in an expansion of their work in micropaleontology. Dr. Miller's micropaleontology course will be expanded next year to three semester hours and will include scheduled lectures both semesters and 2 laboratory periods of three hours each. The course as now constituted will be essentially devoted to a study of fusulinids during one of the two semesters.

Colorado School of Mines

From J. Harlan Johnson, we learn that he is in the midst of completing a large manuscript for State Geological Survey and that during the past year he has published, with K. Konishi, three papers on Silurian and Devonian algae, published in the Colorado School of Mines Quarterly. Also he is the author of a paper entitled "Algal Limestones" published in the Journal of the Paleontological Society of India.

University of Colorado

This correspondent has received no news from the Department of Geology at the University of Colorado, but we are aware that Dr. John Chronic and his wife have returned from a year's exchange teaching at the University of Edinburgh and we are sure that in the future we shall have additional news from this extremely active department of geology, in regard to their micropaleontological research.

University of New Mexico

Dr. Roger Y. Anderson has completed his doctoral dissertation on the pollen and spores from the Kirtland, Ojo Alamo, Nacimiento, and Lewis formations in the San

Juan basin. He is also studying and describing, with the assistance of graduate students, well-preserved abundant foraminifera from the uppermost part of the Lewis shale in the San Juan basin. He reports that the foraminifera occur very near the Cretaceous-Tertiary boundary, and that his students are washing and identifying as much material as possible. Stratigraphic relations and pollen and spore associations suggest that some of the foraminifera may have extended into the Paleocene strata. Dr. Anderson is also in the process of compiling illustrated keys to the several groups of microfossils. He has nearly completed the keys to the smaller foraminifera, conodonts, Paleozoic ostracods and sculptured types of pollen grains and they are now in the stage of final drafting.

P. L. Carten has completed his Master's thesis on Pennsylvanian spores from the Sandia formation, Santa Fe County, New Mexico. It is anticipated that this paper will be published under the supervision of Dr. Anderson in the fall. Mr. Sidney Ash has virtually completed his bibliography of conodonts which now contains over 300 references published since Fay's original catalogue in 1952. William Werrell is continuing his studies of Pennsylvanian ostracodes and his thesis should be completed some time in the coming year.

From the New Mexico Institute of Mining and Technology at Socorro, New Mexico, Dr. Christina Lochman Balk reports that W. E. King of eastern New Mexico School of Mines in Portales, is scheduled to complete his dissertation on the fusulinids of the Dimple limestone of Texas and that he has initiated considerable graduate research activity in micropaleontology at the eastern New Mexico School of Mines.

University of Nevada

Associate Professor Joseph Lintz, Jr., informs this correspondent that his long-range study of the Pennsylvanian system in Nevada is continuing and that he is also continuing his study of the fusulinid foraminifera.

Dr. Lintz will spend the next two years in Java and his work at the University will be temporarily interrupted. Mr. George P. Lloyd has nearly completed his Master's thesis at the University of California at Los Angeles, this work includes the mapping of a portion of the Permian in the White River Valley of Nevada. One of the major oil companies has sponsored this work and Mr. Lloyd has recognized 13 fusulinid genera from the Permian in this area.

University of Utah

Professor Daniel J. Jones is completing his long-term study of the Pleistocene ostracoda of Lake Bonneville and associated sediments and is at present completing the illustrations to accompany the paper. The micropaleontological "highlight" of the year at the University of Utah was the visit on our campus of Professor Tom Barnard of the University of London. Professor Barnard who is well known for his research on the Cretaceous foraminifera of Great Britain delivered two lectures while at the University of Utah. He spoke to the class in micropaleontology on variation in foraminifera and to the Geology Department on the stratigraphy and paleontology of the famous Chalk Series, standard Cretaceous section of England. Mr. Carel L. D. Cohen completed his Master's thesis on the coccoliths and discoasterids from the Mancos shale of eastern Utah and western Colorado (Uinta Basin). Forty six new species of coccoliths and discoasterids were described and six diagnostic species were discovered to be of stratigraphic value in correlating isolated sections of the Mancos shale in the Uinta Basin. Mr. Paul R. Green completed a Master's thesis entitled "Microfauna of the Allen Valley Shale, Central Utah". The Allen Valley shale bridges the boundary between the Greenhorn and the Carlisle divisions of Cretaceous time. The fauna of the Allen Valley consists of 46 species of foraminifera belonging to 23 genera and 2 species of ostracods. Fourteen species of this assemblage are reported for the first time from the Rocky Mountains and 33 species are first reported from the state

of Utah. The ratio of calcareous to arenaceous forms was found to be 4 to 1.

Mr. Carl H. Glismeyer also completed a Master's thesis on the microfauna of the Funk Valley formation of central Utah which is stratigraphically adjacent to the formation studied by Mr. Green. The Allen Valley shale is of Colorado age and is a member of the Indianola group. The 20 genera and 39 species of Foraminifera and the 4 genera and 5 species of ostracodes found in the middle shale member of the Funk Valley formation indicates a lower Niobara (Fort Hayes) age. Ratio of calcareous to arenaceous species of foraminifera is 65% to 35%. The fauna is dominated by the family Lagenidae and by the pelagic foraminifera *Globigerina* and *Gumbelina*. Mr. John Beard is completing a Master's thesis on the foraminifera and ostracoda of the upper Cretaceous section of the Price River Canyon in east-central Utah. Among the foraminifera found was an occurrence of the genus *Kyphopyxa* which is extremely rare in the Cretaceous of Utah. Additional graduate research in micropaleontology includes that of Peter J. Fischer who is completing a Master's thesis on the microfauna of the Tropic formation of southcentral Utah. Mr. Edward Horvath is also completing a Master's thesis on "Fusulinids of the Naco formation of Arizona". This work is being sponsored by a major oil company. Mr. Dwayne D. Stone is continuing work on his doctoral dissertation on the conodont faunas of the Paradox formation in the Colorado Plateau and has found an extremely varied and interesting conodont fauna in the black shales of the Paradox formation. Mr. John Welch of Colorado Western College at Gunnison has virtually completed his doctoral dissertation at the University of Utah on the Pennsylvanian-Permian stratigraphy of central Nevada. Mr. Welch is well known for his work on the fusulinids of the Paradox basin and has employed his knowledge of fusulinids in this thesis investigation.

Dr. Jones anticipates at least 6 new graduate students in the field of mi-

cropaleontology at the University of Utah during the coming year.

Brigham Young University

Professor Keith Rigby reports increased micropaleontological research among graduate students at this institution. Under the direction of Professor Rigby four graduate students are now engaged in studies of the Pennsylvanian and Permian section of extreme western Utah and eastern Nevada. The work will result in systematic studies of the Fusulinidae and other microfossils of the Pennsylvanian-Permian section in this area. Mr. Lloyd Burkell has recently completed a manuscript on the Mississippian Bryozoa of central Utah for his Master's degree. It has been submitted to one of the paleontological journals for publication. Dr. Rigby also reports that Mr. David Clark of Southern Methodist University is currently studying the Devonian conodonts from Utah. Mr. Max Pitcher is planning a systematic stratigraphic study of the Permian fusulinids collected by Dr. Rigby and himself in northern British Columbia. Mr. Pitcher will assist Dr. Rigby during his summer activities in this area. Detailed stratigraphic sections in fusulinid sequences are currently being studied by Mr. Richard Wright on the Pennsylvanian-Oquirrh formation of the Stansbury Mountains to further document the transgressive overlap of the basal portion of the Oquirrh formation in this area.

In addition to the previously mentioned micropaleontological theses there are other theses which will involve aerial mapping of formations in which the fusulinids will be studied. These include Mr. Carl Sandstrom's study of South Mountain southeast of Tooele, Utah, Gerald Robinson in the southern Tintic Mountains and Mr. Harold Winkler's study of the formations of the southern Onaqui Mountains and Mr. Kenneth Johnson who will study the section in the vicinity of Mt. Nebo, Utah. Professor Rigby reports that his own research has narrowed down to a monographic study of the Precambrian to Silurian sponges of North America which he

hopes to complete within 3 years. Professor Harold Bissell is continuing his stratigraphic and paleontological work on the Pennsylvanian and Permian of the Great Basin including the study of the Fusulinidae.

Oil company activities

From Denver, Colorado, J. F. Clement, Jr., reports that the Ohio Oil Company in Littleton, Colorado has employed Mr. Howard Ellis, a graduate of the University of Colorado as micropaleontologist. In general, the micropaleontological activity among oil companies in Denver has decreased somewhat during the past year. Mr. Clements reports that at the present time Carter Oil Co., is doing no micropaleontological work in Denver.

Dr. Grant Steele of the Gulf Oil Corporation in Denver reports to this correspondent that his company has two paleontologists working on the Cretaceous of Wyoming and one on the Pennsylvanian-Permian in the Four Corners area. The Shell Oil Company has five micropaleontologists working in the Denver area. Three are in Casper engaged in studies of the Cretaceous, one is in Grand Junction working on the Cretaceous and the other in Grand Junction is studying the Paleozoic of the Rocky Mountains exclusive of the Paradox Basin. In the Salt Lake City office micropaleo work is being continued by Peter Fischer, Blair Maxfield, and Robert Logan. Mr. James G. Osborne, Jr., senior geologist with the micropaleontological section of the El Paso Natural Gas Co., exploration research laboratory, Salt Lake City, reports that this laboratory now serves all of the exploration divisions within the company. At the present time their studies involve the Paleozoic sections of Texas, New Mexico, Colorado and Utah; and the upper Cretaceous of Wyoming, Colorado, Utah, and New Mexico. Future investigations by the staff of this laboratory will undoubtedly include most of the western United States.

DANIEL J. JONES
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VENEZUELA



BOGUSLAW J. SZENK

Universidad Central de Venezuela

Since the School of Geology was founded in 1938, micropaleontology has been a prescribed course for the degree of "Geologist". This is believed to be unique requirement in South America.

Furthermore, for the first time, micropaleontology is being given as a full year's course, in the fourth year of the five-year course required of geologists. Until now, it had been given as a one-semester course, but in view of the tremendous diversification of the subject in recent years, it was becoming increasingly difficult to give the students even a superficial acquaintance with the microfossils exclusive of foraminifera. Up to 1950, the course first given by Dr. Ely Mencher, then by Mrs. Frances Charlton Rivero, covered only the foraminifera, but when Dr. Pedro Bermúdez gave it in 1950, he extended the content to include other fossils, a plan the School has continued since his transfer to Josepín. On 1959, the School had 9 students in the one-semester course, the last group under the old plan, and 11 in the full-year course. Next year, due to the great increase in registration in geology during the last few years, the School will have about 35 students in micropaleontology, which will severely tax the rather limited laboratory facilities. Fortunately, thanks to donations made by Cía Shell de Venezuela, Ltd. and Creole Petroleum Corporation, the School has acquired several new microscopes.

For the current academic year, the course will again be given by Dr. Bermúdez, who is taking a year's leave of absence from Creole, and will be working part-time with the Ministry of Mines, in the Dirección de Geología, organizing and running their micropaleontological laboratory, and part-time with the University.

An achievement that is hoped to be a stimulus to micropaleontology, not only here but in other Spanish speaking countries, is the forthcoming publication by the University, of two books, on the subject on which Mrs. Charlton Rivero and Dr. Bermúdez have been working for the last three years. Both books are in Spanish, which in view of the extreme scarcity of micropaleontological literature in this language, will fill a real need. One is a general micropaleontology, a fairly simple treatment of the groups for the benefit of beginners, but with extensive bibliographies for the benefit of more advanced workers. The other is a complete treatise on the foraminifera, with descriptions of practically all the genera, and including an extensive chapter on the stratigraphic distribution of the foraminifera in the geologic column in general and in Venezuela in particular. The authors are introducing some changes in the systematic classification, mainly along the line of new superfamilies. The books will probably appear as "Tratado de los Foraminíferos" by Bermúdez and Rivero and "Micropaleontología General" by Rivero and Bermúdez.

The School of Geology is very grateful to the Creole Petroleum Corporation, which in addition to the help on preparation of the plates, was kind enough to permit Dr. Virgil Winkler to give the lectures in micropaleontology this last year in order to allow Mrs. Charlton Rivero more time to work on the book. Mr. Leo Weingeist, also of Creole, was in charge of one of the laboratory sections during the first semester.

The University gives no post-graduate courses in geology but this possibility was always kept in mind,

and if Dr. Bermúdez decides to stay permanently in Caracas a graduate course in micropaleontology may become a reality. It should be mentioned that the students frequently do extensive micropaleontological studies, outside of the formal course, in connection with their final thesis for the degree of "Geologist" which is based on three months' work in the field. However, no doctors' or masters' degrees in geology can be granted by the Universidad Central de Venezuela. One of the students in the regular course this year, Mr. Luis González Silva, has been doing extensive research work on radiolarians from the Querecual formation in which he was able to distinguish 34 different species.

Cia Shell de Venezuela, Ltd.

Shell's Stratigraphic Laboratory for the Western Division in Maracaibo is headed by Dr. A. M. Oosterbaan. His professional staff consists of two palynologists, Dr. J. H. Germeraad and R. de Haan, a micropaleontologist, A. Ford; and a sedimentologist, Dr. J. J. H. C. Houbolt. The palynologists are mostly concerned with the correlation of post-Cretaceous floras in Venezuela, in particular with those of the Maracaibo basin. Messrs. Ford and Houbolt have been engaged mainly in a study of the microfacies of the Cretaceous of western Venezuela which will be presented for publication in the "International Sedimentary Petrographic Series."

Mr. W. E. Crews recently joined the professional staff of Shell's Laboratory in Caracas. He was previously working for Shell in Algeria, Borneo and also Maracaibo.

Creole Petroleum Corporation

The present staff of Creole's Maracaibo Laboratory consists of Dr. Carlos E. Key, in charge, and Messrs. Arthur N. Dusenbury Jr., Jesse J. Howard, Lee B. Gibson, and Peter Ronai. Mr. George Fraunfelder, who specialized in macropaleontology, resigned about a year ago and is a post-graduate student at the University of Missouri. Mr. Lee B. Gibson, specialist in ostracoda,

has resigned and will leave in August to study for his doctor's degree at the University of Oklahoma. Dr. Key prepared a paper on one of the western Venezuela oilfields which he presented at the "Third Venezuelan Congress" late in 1959.

In the past, all of Creole's palynological work has been contracted out to Dr. Robert H. Tschudy, whose laboratory is at Jamestown, Colorado. Recently, the Maracaibo laboratory has been equipped to make the more urgent routine palynological determinations. Mr. Peter Ronai, who worked in the West Indies before joining Creole and whose primary interests are facies problems, is in charge of this operation. Dr. Leonard R. Wilson of Oklahoma University spent June and July, 1959, at the Maracaibo laboratory for the purpose of instructing its staff in the fundamentals of palynology and the latest methods and techniques.

The staff of Creole's Jusepín (Eastern Venezuela) laboratory now consists of Dr. Robert M. Stainforth in charge, and John A. Sulek and James L. Lamb. Dr. Pedro Bermúdez has been granted a leave of absence for one year in order to accept a position with the Dirección de Geología of the Ministerio de Minas e Hidrocarburos in Caracas. He will also teach courses in micropaleontology at the Universidad Central de Venezuela. Dr. Stainforth prepared a paper on Oligo-Miocene pelagic foraminifera for presentation at the "Third Venezuelan Geological Congress". Mr. Gordon M. Sowers, former head of the Jusepín laboratory has left Venezuela and is now living in Miami, Florida.

Mene Grande Oil Company

Professor Gunnar Erdtman of Stockholm, one of the world's foremost palynologists, spent six days in Caracas early in 1959, at the invitation of Mene Grande, Shell and Mobil Oil Co. During his stay Prof. Erdtman gave a lecture on "Modern Methods in Palynology" for the Asociación Venezolana de Geología, Minería

y Petróleo. Prof. Erdtman's advice and suggestions will be very valuable in future palynological work in Venezuela.

Mene Grande's Stratigraphic Laboratory consists of the following professional staff: Dr. H. H. Renz, director, Wade H. Hadley, studying stratigraphy of Eastern Venezuela, George Fournier, head of the palynological section, Alejandro Euribe, working on biostratigraphy from surface samples, Ernest Murany and P. Parenti studying surface geology, Luis M. Banks, mineralogist, Gordon A. Young and Dr. B. J. Szenk working on stratigraphy of Western Venezuela.

In February, 1959, Dr. H. H. Renz made a trip to Trinidad and collected samples to complete Mene Grande's type collection of pelagic foraminifera. Excursions were made jointly with Drs. Amos Salvador and R. M. Stainforth of Creole in the Pointe-à-Pierre - San Fernando and Eastern Central Range areas. Dr. Hans Kugler of Texaco directed some of the excursions and showed the new geological map of Trinidad to the visitors. Stratigraphic problems of common interest were discussed.

Mr. Maurice Leroy, a micropaleontologist of the "Société Africaine des Pétroles" at Dakar, Sénégal, West Africa, spent a few days in Caracas to discuss with Dr. Renz the stratigraphy and correlation of Gulf's wells in Ghana, with SAP's Ivory Coast well. Following Mr. Leroy's visit, Mr. Michel Tenaille, president of SAP also visited Mene Grande's Stratigraphic Laboratory in Caracas.

Dr. H. H. Renz and G. Fournier accepted an invitation by the International Petroleum Co. Ltd. to visit their laboratory in Bogotá, Colombia, where they discussed stratigraphic questions of common interest with Dr. V. Petters, Ray Malloy and others.

Mene Grande's Palynology Section of the Stratigraphic Laboratory started routine operations at the beginning of 1959.

Venezuelan Atlantic Refining Company

Dr. Hans M. Bolli is in charge of VARCO's micropaleontological work in Venezuela. He is presently engaged in a joint study with Dr. M. B. Cita of the University of Milano on the upper Cretaceous and lower Tertiary planktonic foraminifera from the Paderno d'Adda section in northern Italy.

Mobil Oil Company of Venezuela

Messrs. Foster D. Smith, Jr. and Stephen F. Percival, Jr. are assigned to the Regional Section of the Mobil Oil Co. and are stationed in Anaco in eastern Venezuela.

Foster D. Smith Jr. is in charge of the section and is working on the regional geology and micropaleontology of the eastern Venezuela basin. Mr. Percival is working on the micropaleontology of western Vene-

zuela and is studying the pelagic foraminifera of the Caribbean area.

Richmond Exploration Company

Richmond's laboratory at Maracaibo is staffed by Robert Jaroska and A. B. Whitman. Current work is primarily concerned with correlations, stratigraphy, and regional problems related to the Richmond Exploration Company's concessions in western and eastern Venezuela.

Independent laboratories

Mr. Frank Amato is currently engaged in routine paleontologic and lithologic studies with emphasis on the stratigraphy of northeastern Venezuela and Trinidad. The Laboratory is also engaged in processing, i.e. washing, picking, thin-sectioning and storage for those companies who do not wish to establish and maintain a complete paleo-laboratory in Venezuela.

Research in palynology has been shelved pending completion of current routine studies.

The consulting laboratory now consists of Mr. Amato, stratigrapher-micropaleontologist, and one assistant trainee micropaleontologist.

Others

Dr. Jean Marc Sellier de Civrieux, previously in charge of all micropaleontological work in the Ministry of Mines and Hydrocarbons, was recently appointed chief of the Division of Geological Documentation of the Ministry.

Dr. A.E. Wirz, chief paleontologist of Pan Venezuelan Oil Company was transferred, effective 1 August 1959, to assist the company's operations in Iran.

BOGUSLAW J. SZENK
Mene Grande Oil Company,
Caracas

Directory of correspondents

The following list of correspondents is presented for the benefit of those who wish to submit news items for publication in this quarterly. Contributors should send such news items to the correspondents reporting for their own areas. Manuscripts of papers submitted for publication should *not* be sent to correspondents. They should be submitted to: Department of Micropaleontology, American Museum of Natural History, Central Park West at 79th. Street, New York 24, N.Y.

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